D.C. DEPARTMENT OF HEALTH
Environmental Health Administration
Bureau of Environmental Quality
Water Quality Division

DISTRICT OF COLUMBIA SMALL TRIBUTARIES TOTAL MAXIMUM DAILY LOAD MODEL FINAL REPORT

July 2003

Government of the
District of Columbia
Anthony A. Williams, Mayor

D.C. DEPARTMENT OF HEALTH
ENVIRONMENTAL HEALTH ADMINISTRATION
BUREAU OF ENVIRONMENTAL QUALITY
WATER QUALITY DIVISION

DISTRICT OF COLUMBIA SMALL TRIBUTARIES TOTAL MAXIMUM DAILY LOAD MODEL FINAL REPORT

PREPARED BY

Interstate Commission on the Potomac River Basin

JULY 2003

This publication has been prepared by the Interstate Commission on the Potomac River Basin in support of District of Columbia Grant No. 01a-02-amWQD02 (APPR01). Additional funds for this publication were provided the Anacostia Watershed Toxics Alliance, and by the signatory bodies to the Interstate Commission on the Potomac River Basin: Maryland, Pennsylvania, Virginia, West Virginia, and the District of Columbia. The opinions expressed are those of the authors and should not be construed as representing the opinions or policies of the United States or any of its agencies, the several states, or the Commissioners of the Interstate Commission on the Potomac River Basin.

This publication is also available from the Interstate Commission on the Potomac River Basin as ICPRB Report No. 03-3.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

The District of Columbia is fortunate to have a rich system of rivers and streams flowing within its boundaries. The three largest of these, the Potomac River, the Anacostia River and Rock Creek, each have within their basins a network of smaller tributaries which also provide habitat for aquatic life and provide recreational opportunities for District residents and visitors. However, these small tributaries suffer from a wide variety of problems typical of urban streams. Because of the large areas of paved or otherwise impervious surfaces present in urban areas, most of these streams experience unnaturally high flows during storm events, resulting in eroded stream banks and channels. Many of them have had large portions of their lengths re-routed into artificial channels or diverted into underground sewer pipes, leaving only a small portion of the original stream flowing through a natural above-ground stream bed. Additionally, during storm events a variety of pollutants, including bacteria, organic matter, nutrients, and toxic chemicals, are washed off the city's lawns, streets, parking lots, and other surfaces and are discharged into these streams by the city's sewer systems. The District of Columbia's 303(d) list of water bodies not meeting applicable water quality standards includes many small tributaries of the Potomac, the Anacostia, and Rock Creek. Causes of impairments are given as organics, bacteria, metals, and/or total suspended solids (TSS). Under the Clean Water Act, the District Government must determine the Total Maximum Daily Load (TMDL) for each of these streams for each pollutant.

In order to assist the DC DOH in its program to develop TMDLs for District streams, ICPRB has constructed a simple mass balance model, the DC Small Tributaries TMDL Model, which estimates concentrations of toxic pollutants and bacteria for 23 small streams on the District's 303(d) list. In order to address the three types of constituents believed to cause impairments, this model is composed of three sub-models: an organic chemicals sub-model for chlordane, dieldrin, heptachlor epoxide, DDT, PAHs, PCBs; an inorganic chemicals sub-model for zinc, lead, copper, arsenic; and a sub-model for fecal coliform bacteria. These sub-models predict daily water column concentrations of each constituent in each of the 23 streams under current conditions and under potential pollution load reduction scenarios.

The DC Small Tributary TMDL Model does a fair job in simulating daily concentrations of modeled constituents. based on comparisons of model results with available data In plots of predicted versus observed concentrations of zinc, lead, copper, and fecal coliform for Hickey Run and Watts Branch, the two streams for which the most data are available, model predictions fall reasonably close to observed values for the majority of the data points. However, the model is unable to simulate many of the highest concentration values reported in the available data sets.

Because of the limited amount of data for the 23 tributaries modeled, several significant simplifications have been made which contribute to errors in the model's predictive capabilities. Additional data would improve our understanding of toxic chemicals in the District's small streams. Collection of bed sediment data, water column data, and additional storm water monitoring data for toxic chemicals would be useful in determining whether or not District Water Quality Standards are being met and would support the development of more accurate predictive models.

I. Introduction

The District of Columbia is fortunate to have a rich system of rivers and streams flowing within its boundaries. The three largest of these, the Potomac River, the Anacostia River and Rock Creek, each have within their basins a network of smaller tributaries which also provide habitat for aquatic life and provide recreational opportunities for District residents and visitors. However, these small tributaries suffer from a wide variety of problems typical of urban streams. Because of the large areas of paved or otherwise impervious surfaces present in urban areas, most of these streams experience unnaturally high flows during storm events, resulting in eroded stream banks and channels. Many of them have had large portions of their lengths re-routed into artificial channels or diverted into underground sewer pipes, leaving only a small portion of the original stream flowing along a natural above-ground stream bed. Additionally, during storm events a variety of pollutants, including bacteria, organic matter, nutrients, and toxic chemicals, are washed off the city's lawns, streets, parking lots, and other surfaces and are discharged into these streams by the city's sewer systems. In a recent bioassessment and habitat assessment of the District's small streams (Banta, 1993), over half were rated "Severely Impaired" and the rest were rated "Moderately Impaired". In this study, it was found that for most streams, the evidence suggested that toxic chemicals played a role in the impairments.

The District of Columbia's 303(d) list of water bodies not meeting applicable water quality standards includes the 23 small tributaries of the Potomac, the Anacostia, and Rock Creek listed in Table 1 and depicted in Figures 1a and 1b. Causes of impairments are given as organics, bacteria, metals, and/or total suspended solids (TSS). Under the Clean Water Act, the District Government must determine the Total Maximum Daily Load (TMDL) for each of these streams for each pollutant. The TMDL provides an estimate of the maximum amount of a pollutant, taking into account a reasonable margin of safety, which can be discharged into a water body without causing a violation of applicable water quality standards.

The District's Environmental Health Administration of the Department of Health (DOH) requested that the Interstate Commission on the Potomac River Basin (ICPRB) assist it in the development of TMDL allocations by constructing a computer model that could estimate concentrations of organic chemicals, metals, and fecal coliform bacteria in the 23 small tributaries under a variety of potential load reduction scenarios. For this purpose, ICPRB has constructed a simple mass balance model, the "District of Columbia Small Tributaries Total Maximum Daily Load Model", developed as an application in Microsoft ACCESS. Details concerning model construction and model results are given in the sections that follow.

I.1. Background

The District of Columbia lies in two physiographic provinces, the Piedmont and the Coastal Plain, with the geologic transition between the two areas, referred to as the "fall line", running through the Northwestern portion of the city roughly parallel to Rock Creek, and then Northeast through the Luzon Branch watershed (Banta, 1993). The Piedmont province is characterized by gently rolling hills, with soils underlain by hard crystalline rocks. The Coastal Plain province is characterized by a flatter, terraced landscape, formed by unconsolidated sedimentary deposits of sands, clays, and gravels. Piedmont streams tend to be steeper and faster flowing than the meandering streams of the Coastal Plain. All of the tributaries to the Anacostia shown in Figure 1a have drainage basins within the Coastal Plain province. All of the tributaries of Rock Creek and the Potomac shown in Figure 1b are primarily within the Piedmont, with the exception of Piney Branch, whose drainage basin lies within the Coastal Plain.

The District of Columbia occupies a land area of 61 square miles with a population of approximately 572,000 (US Census, 2002). According to information available from the Metropolitan Washington Council of Governments (MWCOG), land use in the District is approximately 45 % low-medium density residential, 3 % medium-high density residential, 7 % institutional, 7 % Federal, 4 % commercial, 3 % industrial, 5 % mixed use, and 25 % parkland, with impervious surfaces covering approximately 33% of the land area overall. Many of the 23 small tributaries listed in Table 1 are surrounded, at least in part, by parkland. In the sub-watersheds of these tributaries, parks and low to medium density residential land uses predominate. Land use in the District is depicted in Figure 2.

Most, if not all, of the streams listed in Table 1 have had some portion of their original lengths re-routed into underground sewer pipes. Some originate at a sewer outfall and disappear into a storm drain after traveling above ground for only a brief time. Along or near the banks of all of these streams are outfalls of the city's separate storm (SS) sewer system, and during storms these outfalls discharge water that has washed off of nearby lawns, rooftops, streets, and parking lots. The trace quantities of sediment, organic matter, toxic chemicals, and bacteria carried by this water, often referred to as "non-point source" pollution, are believed to be the primary cause of the impairments identified in these streams. One of the 23 tributaries, Piney Branch, has a sub-shed partly located in the portion of the city served by the combined sanitary and storm (CSS) sewer system, and during some storm events, CSS system overflows (CSOs) discharge into Piney Branch.

I.2. Model Framework

In order to assist the DC DOH in its program to develop TMDLs for District streams, ICPRB has constructed a simple mass balance model, the DC Small Tributaries TMDL Model, which estimates concentrations of toxic pollutants and bacteria in the 23 streams listed in Table 1. In order to address the three types of constituents believed to cause impairments, this model is composed of the following three sub-models:

1) Organic chemicals sub-model: chlordane, dieldrin, heptachlor epoxide, DDT, PAHs, PCBs
2) Inorganic chemicals sub-model: zinc, lead, copper, arsenic
3) Bacteria sub-model: fecal coliform bacteria

These sub-models predict daily water column concentrations of each constituent in each of the 23 streams under current conditions and under potential pollutant load reduction scenarios. Because little data exists concerning the presence or the concentrations of specific toxic chemicals in these streams, the list of constituents modeled was taken from the list of constituents addressed in the District's Anacostia River TMDL for toxic chemicals (Behm et al. 2003). The constituents of the organic chemicals sub-model include the pesticides, chlordane, dieldrin, heptachlor epoxide, and dichloro-diphenyl-trichloroethane (DDT), none of which are currently in use. The organic chemicals sub-model also includes polycyclic aromatic hydrocarbons (PAHs), a class of chemicals present in coal, motor oils, gasoline, and their combustion products, and polychlorinated biphenyls (PCBs), the chemical constituents of a type of heavy oil that was formerly used in transformers, capacitors, heat exchangers, fluorescent light bulbs, and other products. The constituents of the inorganic chemicals sub-model are arsenic, which is has been used in pesticides, herbicides and wood preservatives, lead, which has been used as an additive in paints and gasoline, and also the metals, zinc and copper. The bacteria sub-model simulates concentrations of fecal coliform, a relatively harmless bacteria that is used as an indicator of the presence of human and non-human fecal matter and associated pathogens in natural water bodies. A more detailed description of the constituents included in the sub-models is given in the next section.

The simulation is carried out using the most recent available monitoring data to estimate base flow and storm flow constituent concentrations and using ICPRB's Watts Branch HSPF (Hydrologic Simulation Program - FORTRAN) model output to estimate storm and base flow input volumes (Mandel and Schultz, 2000). For TMDL model runs to evaluate potential load reduction scenarios, the Watts Branch HSPF model uses precipitation data for the three-year time period, 1988, 1989, and 1990. This time period includes a relatively wet year, a relatively dry year, and an average precipitation year, and has been used in a number of studies to represent a typical range of hydrologic conditions (Mandel and Schultz, 2000; DCWASA, 2002).

I.3. Data Support

For the most part, little actual data exists concerning concentrations of toxic chemicals in the small tributaries listed in Table 1. The data which does exist is primarily for metals, since most commercial laboratories still do not have the ability to measure toxic organic chemicals at the very low concentrations at which they are typically found in streams and in storm water runoff. At the time of preparation of this report, ICPRB is not aware of any published studies which have measured concentrations of the toxic chemicals listed in Section 1.2 in any of the small tributary bed sediments. Also, there appear to be no studies which provide useful data on water column concentrations of organic chemicals in any of these streams. However, there are several studies which provide data on water column concentrations of metals and of fecal coliform bacteria in a number of the streams listed in Table 1. Additionally, there have been a number of storm water monitoring studies in the greater metropolitan area that have measured concentrations of toxic chemicals and other constituents contained in water discharging into District streams. Brief descriptions of the main data sets used in the DC Small Tributaries TMDL Model are given below:

- <u>Northeast/Northwest Branch study</u> (Gruessner et al.,1998) ICPRB conducted a study for DC DOH on toxic chemical concentrations in the upstream tributaries to the Anacostia, the Northeast and Northwest Branches. For this study, water samples were collected from both tributaries in 1995-96 during four storm events and six non-storm events and concentration values were reported for all chemicals modeled except arsenic. Chemical analyses were performed at extremely low detection limits. Sample collection locations were at the US Geological Survey (USGS) Northeast Branch and Northwest Branch gage stations, Stations 01649500 and 0165100, located in Maryland not far from the District boundary.

- DC MS4 monitoring program (Nicoline Shelterbrandt, private communication, 2002) The Water Quality Division of the DC DOH is conducting Municipal Separate Storm Sewer System (MS4) monitoring at a number of locations as part of the requirements for the District's National Pollutant Discharge Elimination System (NPDES) permit (MS4 NPDES Permit No. DC0000221, First Annual Review, Volume III). MS4 monitoring data available to ICPRB at the time of this report were collected from June 1, 2001 through June 13, 2002 at the following locations in the Anacostia tidal basin: Stickfoot sewer, O St. pumping station (separate sewer line), Gallatin at 14 St., Varnum and 19th Place (later Varnum and 22nd Place), Nash Run, Hickey Run at V St. and 33rd St., Oklahoma and D St., and East Capitol Street (west). Detection limits used for analyses of metals and of some organic chemicals were low enough to measure concentrations of these chemicals in storm water.

- DC Water and Sewer Authority Long Term Control Plan monitoring The DC Water and Sewer Authority (DC WASA) conducted monitoring of storm water discharges from CSOs as well as some tributaries and separate storm sewer system locations, in 1999 and 2000 in support of its development of its Long Term Control Plan (LTCP) to address the CSO problem (DC WASA, 2000a; 2000b). Though the primary aim of the monitoring study was to better understand loads of constituents contributing to the dissolved oxygen problem in the Anacostia and Potomac, some analyses were also done for metals and toxic organic chemicals. Detection limits used for analyses of metals were low enough to measure concentrations of these chemicals in storm water.

- DC routine monitoring program (Cliff Jarmon, private communication) The DC DOH collects and analyses water samples from District streams on a regular basis. DC DOH provided ICPRB with data from this program for the time period, January 1995 through July 2000, including data for the metals, zinc, lead, and copper. Data are also available for arsenic, but it was not used in this modeling effort because all arsenic concentrations in the data set are reported to be below the quantification limit.

Data from the first three of the studies listed above have been used to estimate the concentrations of toxic chemicals contained in storm water discharging into the small tributaries, and in base flow water in the streams. Additionally, data for Hickey Run from the DC WASA LTCP monitoring program, combined with data from the DC routine monitoring program, are used in Section III of this report to assess the ability of the model to predict concentrations of metals and of fecal coliform bacteria in the small tributaries.

Table 1. Small Tributaries on the District of Columbia's 303(d) List

Tributary	Receiving Water	Included in Organic Chemicals Sub-Model	Included in Fecal Coliform Sub-Model	Included in Inorganic Chemicals Sub-Model
Fort Chaplin	Anacostia River		✔	✔
Fort Davis	Anacostia River		✔	✔
Fort Dupont	Anacostia River		✔	✔
Fort Stanton	Anacostia River	✔	✔	✔
Hickey Run	Anacostia River	✔	✔	
Nash Run	Anacostia River	✔	✔	✔
Popes Br	Anacostia River	✔	✔	✔
Texas Ave Trib	Anacostia River	✔	✔	✔
Watts Br	Anacostia River	✔	✔	
Battery Kemble/Fletchers Run	Potomac River		✔	✔
Dalecarlia Trib	Potomac River	✔	✔	
Foundry Br	Potomac River		✔	✔
Broad Br	Rock Creek	✔		
Dumbarton Oaks	Rock Creek	✔		
Fenwick Br	Rock Creek	✔		
Klingle Valley	Rock Creek	✔		
Luzon Cr	Rock Creek	✔		
Melvin-Hazen Cr	Rock Creek	✔		
Normanstone Cr	Rock Creek	✔		
Piney Br	Rock Creek	✔		✔
Pinehurst Br	Rock Creek	✔		
Portal Br	Rock Creek	✔		
Soapstone Cr	Rock Creek	✔		

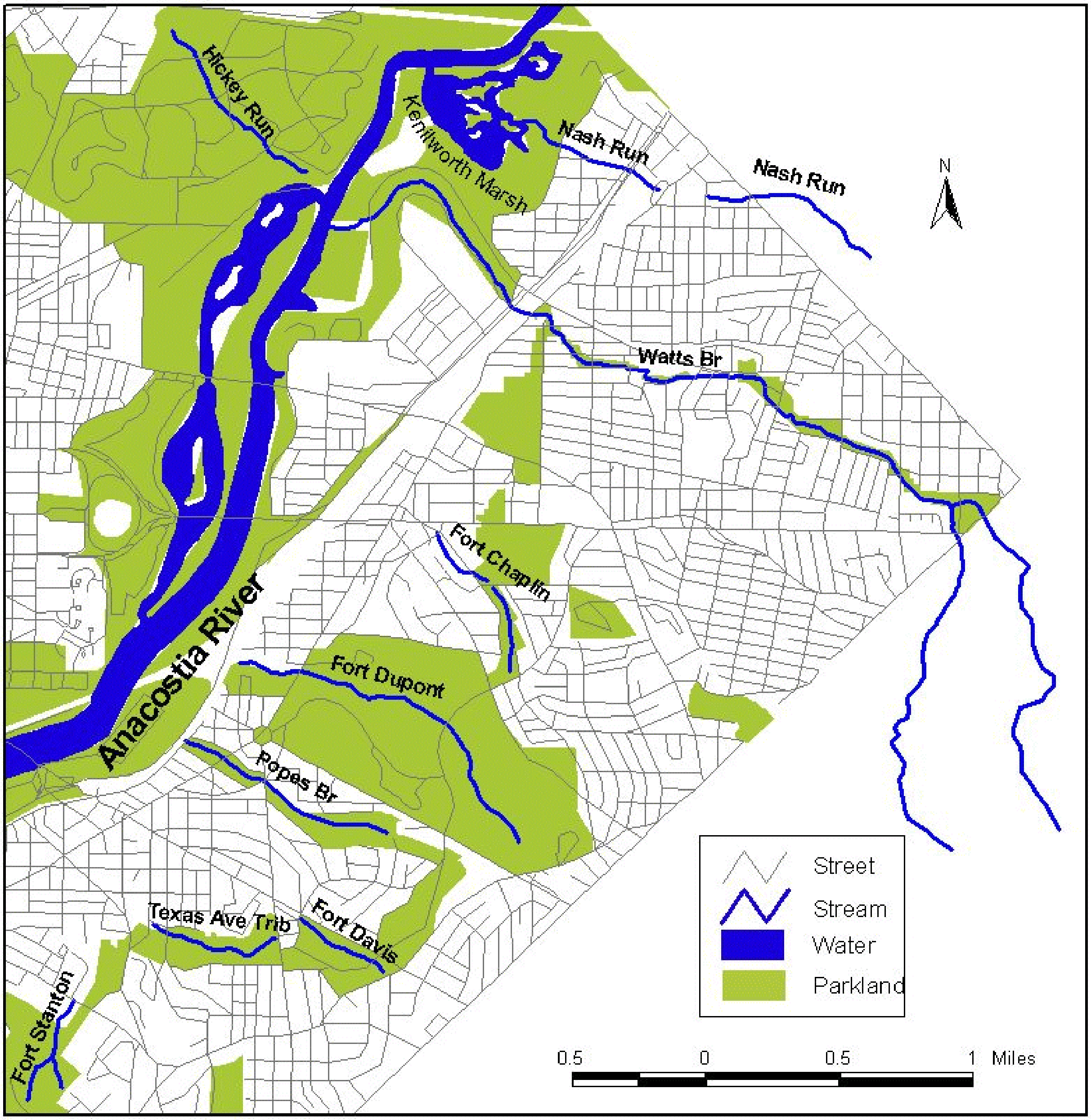

Figure 1a. Small Tributaries of the Anacostia River

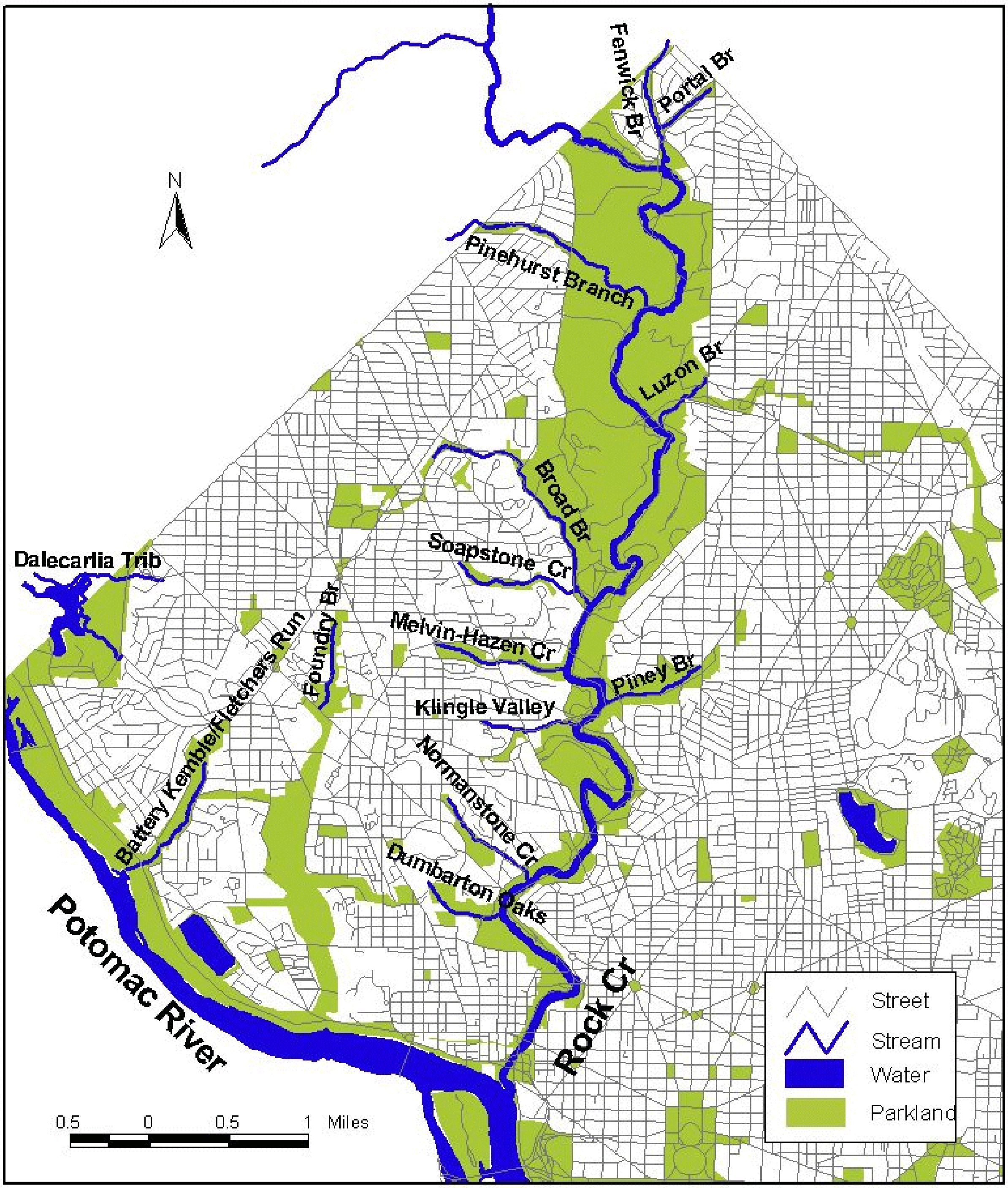

Figure 1b. Small Tributaries of Rock Creek and the Potomac River

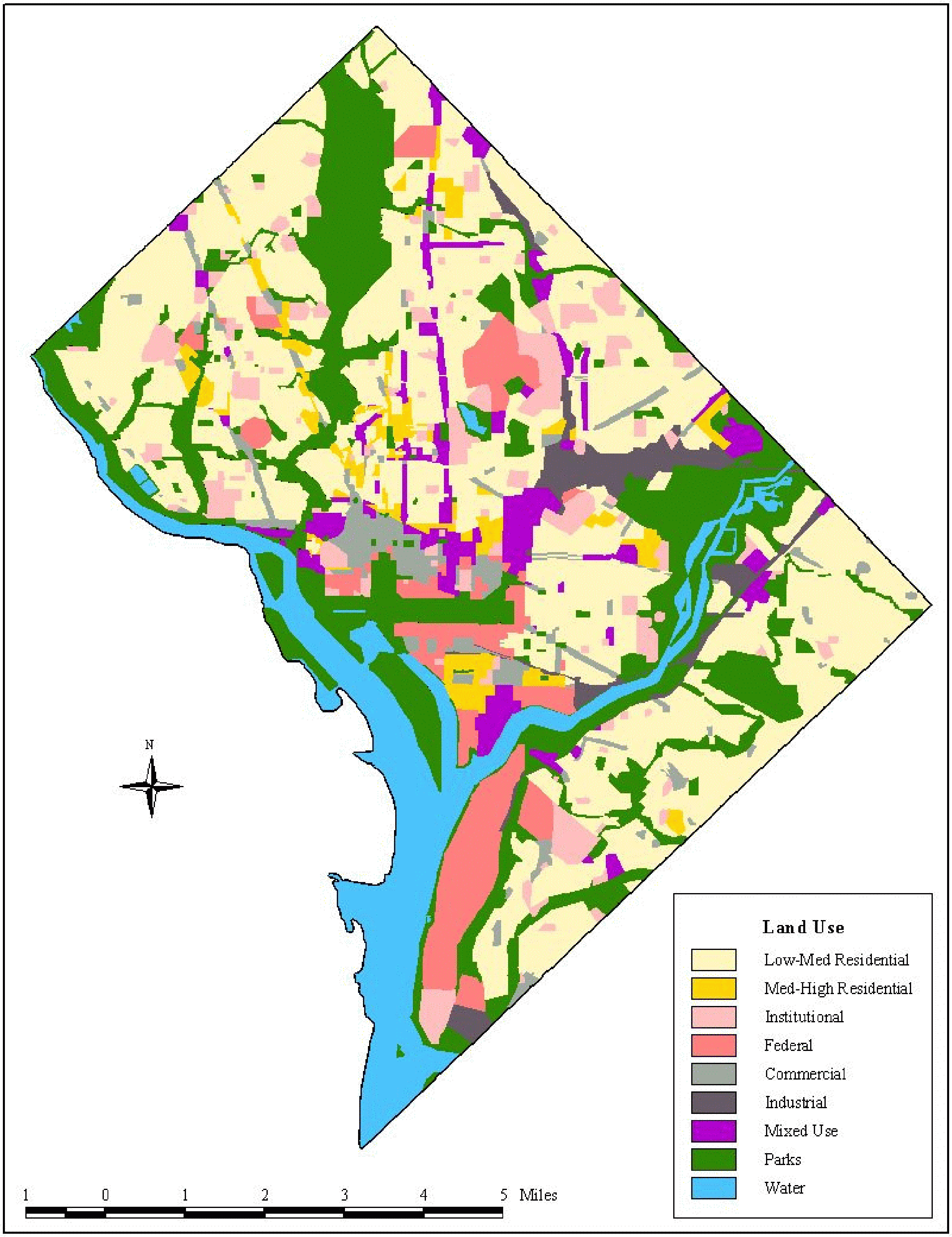

Figure 2. Land Use in the District of Columbia

II. Model Description

The DC Small Tributaries TMDL Model is a simple mass balance model which predicts daily water column concentrations of each of the modeled constituents in each of the 23 tributaries listed in Table 1. The model treats each tributary as essentially a "bathtub" which, on each day of the simulation period, receives a volume of water representing storm water runoff and a volume of water representing base flow from groundwater infiltration from that tributary's drainage area. Each of these volumes of water flowing into a tributary is assumed to contain a quantity of each of the modeled constituents, based on average concentrations measured in available storm water and base flow monitoring data. Each day's storm water volume and base flow volumes are assumed to be completely mixed within each tributary, and no additional in-stream processes, such as sediment resuspension or loss of contaminants via volatilization, are simulated. This modeling framework was judged by ICPRB to be appropriate given the amount of data available to support model development.

II.1. Model Constituents

A list of constituents represented in the three sub-models are given in Tables 2a, 2b, and 2c. Because little data exists for toxic chemical concentrations in these small streams, the chemicals represented are the same as those included in the District's TMDL model for toxic chemicals in the Anacostia River, the TAM/WASP Toxics Screening Level Model (Behm et al., 2003). In the organic chemicals sub-model, Total Chlordane represents the sum of three chlordane species or metabolites for which sufficient data are available: cis-chlordane + trans-nonachlor + oxychlordane. The three species or metabolites of DDT for which sufficient data are available, 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT, are modeled individually. Also, in the organic chemical sub-model, sixteen PAHs for which sufficient data are available have been grouped into three different classes, as was done in the Anacostia TMDL model. The first group, PAH1, is the sum of six 2 and 3-ring PAHs, naphthalene, 2-methyl napthalene, acenapthylene, acenapthene, fluorene, and phenanthrene. The second group, PAH2, consists of the four 4-ring PAHs, fluoranthene, pyrene, benz[a]anthracene, and chrysene. The third group, PAH3, consists of the six 5 and 6-ring PAHS, benzo[k]fluoranthene, benzo[a]pyrene, perylene, indeno[1,2,3-c,d]pyrene, benzo[g,h,i]perylene, and dibenz[a,h+ac]anthracene. PCBs refer to a class of 209 distinct chemicals referred to as PCB congeners. Because District water quality standards for PCBs apply to total PCBs only, the organic chemicals sub-model groups all PCB congeners into a single class, total PCBs, representing the sum of all congeners.

II.1.1. District of Columbia Water Quality Standards

Tables 2a, 2b, and 2c contain District of Columbia Water Quality Standards (WQS) for the modeled constituents. These standards are given in Chapter 11 of Title 21 of the District of Columbia Municipal Regulations, as amended on February 22, 2002 (49 DCR 1706). Water quality standards are specified for each of the designated beneficial use classifications:

- Class A: Primary contact recreation
- Class B: Secondary contact recreation and aesthetic enjoyment
- Class C: Protection & propagation of fish, shellfish and wildlife
- Class D: Protection of human health related to consumption of fish & shell fish
- Class E: Navigation

All of the streams listed in Table 1 have designated uses of Class A, B, C, and D waters, with the exception of Hickey Run and Watts Branch, which have designated uses of Class B, C, and D waters. Because model predictions for PAH1, PAH2, and PAH3 all represent sums of groups of PAHs, the conservative assumption was made that applicable WQS are the most stringent standard for a single PAH in the group. For example, the published Class D WQS for fluoranthene, pyrene, benz[a]anthracene, and chrysene are 370, 11000, 0.031, and 0.031 ug/l, respectively. Therefore the most stringent of the individual standards, 0.031 ug/l, is given in Table 2a as the Class D standard for PAH2.

For the inorganic constituents, zinc, lead, and copper, the Class C Criteria Maximum Concentration (CMC) and Criteria Continuous Concentration (CCC) standards given in Table 2b have been computed from the published District of Columbia standards assuming a hardness of 169 mg/L as $CaCO_3$, the mean hardness computed from recent (1998-2000) DC DOH routine monitoring data.

The DC Small Tributaries TMDL Model, in addition to predicting daily water column concentrations of modeled constituents, also compares these concentrations to the WQS appearing in Tables 2a, 2b, and 2c in order to predict on how many days WQS are violated during the three-year simulation period. Using the published WQS as a guideline, four-day averages of predicted concentrations are used to compare with Class C CCC standards, and 30-day averages of predicted concentration are used to compare with Class D standards.

II.1.2. Model Concentration Estimates

Tables 2a, 2b, and 2c contain constituent concentration estimates that were used as model inputs to represent concentrations in stream base flow, separate sewer system storm flow, and CSOs discharging into the 23 small tributaries. These estimates were computed using data from the Northeast/Northwest Branches study, the DC MS4 monitoring program, and the DC WASA LTCP monitoring program, described in more detail in Section I.3, above. Because very little data exists for the 23 small streams, these values represent estimates of city-wide average concentrations. The base flow, storm flow, and CSOs concentration values for organic chemicals and metals in Tables 2a and 2b are consistent with those used for the separate sewer system and minor tributary ("SSTRIB") concentration inputs and Watts Branch concentration inputs for ICPRB's TMDL model for toxic chemicals in the Anacostia River. More details on how these estimates were computed can be found in the report on that model (Behm et al., 2003). The average storm water concentration estimate for fecal coliform bacteria was obtained from District MS4 monitoring data (Nicoline Shelterbrandt, private communication). The mean Rock Creek base flow fecal coliform concentration from DC WASA LTCP monitoring program was used as an estimate for small tributary baseflow concentrations (DC WASA, 2002).

Table 2a. Constituents of the DC Small Tributary Organic Chemicals Sub-Model

Constituent	Base Flow Conc. (µg/L, dissolved + particulate)	Storm Flow Conc. (µg/L, dissolved + particulate)	CSO Conc. (µg/L, dissolved + particulate)	Class C WQS - CCC (µg/L, dissolved + particulate)	Class C WQS - CMC (µg/L, dissolved + particulate)	Class D WQS (µg/L, dissolved + particulate)
Total Chlordane	0.000963	0.00983	0.00983	0.004	2.4	0.00059
4,4'-DDD	0.00462	0.003	0.003	0.001	1.1	0.00059
4,4'-DDE	0.00393	0.0133	0.0133	0.001	1.1	0.00059
4,4'-DDT (Watts Br only)	0.01226 (0.00061)	0.0342 (0.00171)	0.0342 (NA)	0.001	1.1	0.00059
Dieldrin	0.000641	0.00029	0.00029	0.0019	2.5	0.00014
Heptachlor Epoxide	0.000641	0.000957	0.000957	0.0038	0.52	0.00011
PAH1	0.0825	0.6585	0.6585	50	NA	14000
PAH2	0.219	4.1595	4.1595	400	NA	0.031
PAH3	0.1065	2.682	2.682	NA	NA	0.031
Total PCBs	0.0115	0.0806	0.0806	0.014	NA	0.000045

Table 2b. Constituents of the DC Small Tributary Inorganic Chemicals Sub-Model

Constituent	Baseflow Conc. (µg/L, dissolved + particulate)	Stormflow Conc. (µg/L, dissolved + particulate)	CSO Conc. (µg/L, dissolved + particulate)	Class C WQS - CCC[1] (µg/L, dissolved)	Class C WQS - CMC[1] (µg/L, dissolved)	Class D WQS (µg/L, dissolved)
Zinc	7.5	173	213	165.3	182.5	NA
Lead	0.6	29	80	6.2	159.2	NA
Copper	3.5	57	76	18.5	29.1	NA
Arsenic	0.2	1.4	1.4	150	340	0.14

[1] Zinc, lead, and copper values computed from the published District of Columbia standards assuming a hardness of 169 mg/L as CaCO3.

Table 2c. Constituents of the DC Small Tributary Bacteria Sub-Model

Constituent	Baseflow Conc. (Number /100 mL)	Stormflow Conc. (Number /100 mL)	CSO Conc. (Number /100 mL)	Class A WQS (Number /100 mL)	Class B WQS (Number /100 mL)
Fecal coliform bacteria	280	17300	NA	200	1000

II.2. Daily Flow Volume Estimates

Daily estimates of base flow and storm flow volumes discharging into each tributary were made using ICPRB's Watts Branch HSPF model along with information from a land use analysis for each of the 23 small tributary sub-watersheds. (Additionally, in the case of Piney Branch, CSO discharges were also included in the model simulations; see below.) An HSPF model simulates hydrologic processes, such as infiltration, evapotranspiration, surface runoff, and ground water flow, from a watershed based on land use within the shed boundaries and on local precipitation and other climatic data. For model TMDL runs to evaluate potential load reduction scenarios, the three year time period, 1988-90, is used in the model to represent a typical range of climate conditions. In the Watts Branch HSPF model, described in detail in Mandel and Schultz (2000), all land within the Watts Branch sub-shed is categorized into three land use categories: 1) Impervious; 2) Urban Pervious; and 3) Forested Pervious. The model can be used to predict, for each category, the daily flow volume per unit area of both base flow and surface runoff (i.e., storm flow). The Watts Branch HSPF model was calibrated by ICPRB using stream discharge data from the USGS gage station 01658000 on the Watts Branch near Minnesota Avenue, which has been in operation since June 1992. ICPRB originally constructed the Watts Branch HSPF model to help provide flow inputs for its Anacostia River models because the Watts Branch is the only stream in the District of Columbia with a long-term record of stream discharge.

The Watts Branch HSPF model can be used to estimate daily flow volumes entering other DC small tributaries under the assumption that these nearby urban sub-sheds have hydrologic properties similar to those of the Watts Branch sub-shed. This assumption is certainly appropriate for the impervious areas of the city, that is, rooftops, roadways, parking lots, etc. It is also probably appropriate for much of the "urban pervious" areas, since it is reasonable to assume that human activities have had a significant and relatively uniform impact on the urban landscape throughout the DC metropolitan area. The assumption is least appropriate for the remaining areas of the city which have experienced little disturbance from human activities.

In order to use the Watts Branch HSPF model output to estimate daily flow volumes to the other small tributaries listed in Table 1, it is necessary to know the area of each of the three model land use categories contained in each tributary's sub-shed. ICPRB computed estimates for these areas by first delineating the sub-shed boundaries, and then computing total areas within in sub-shed of each of the land use types depicted in Figure 2, that is, low-medium density residential, medium-high density residential, institutional, Federal, commercial, industrial, mixed use, and parkland, impervious, urban pervious, and forested. Finally, available information on the percentage of impervious area for each land use types was used to compute areas of the model land use categories, impervious and urban pervious. (No areas of the third model land use category, pervious forested, were found in any of the small tributary sub-sheds with the exception of Watts Branch.) Results of land use analyses are given in Tables 3 and 4. ICPRB did not delineate sub-shed boundaries for the two Anacostia River tributaries with substantial portions of their areas in Maryland, Watts Branch and Nash Run, but rather, used the delineations available from MWCOG that were also used in ICPRB's TAM/WASP model for the Anacostia River. For the other 21 tributaries, sub-sheds were delineated by ICPRB based on a combination of topographic information and information on the sewer outfalls discharging into the stream and their associated drainage areas, along with a certain amount of "best engineering judgement". Topographic information was obtained from digital images of USGS 7.5 minute quad maps, and information on the location of DC separate sewer system outfalls and associated drainage areas, or sewer-sheds, was provided by LimnoTech, Inc. (LTI) (private communication, Scott Rybarzik). The land use analysis was performed using DC land use information obtained from MWCOG, and the Environmental Systems Research Institute, Inc. software, ArcView and Spatial Analyst.

A number of the 23 tributaries have sub-sheds which lie partially in Maryland. With the exception of the Watts Branch and Nash Run, where MWCOG delineations of sub-watershed were available, ICPRB used topographic information to delineate the Maryland portion of the sub-sheds. Additionally, land use in the Maryland portion was assumed to be similar to land use in the District portion of these sub-sheds. ICPRB estimates of the Maryland portion of the small tributary sub-sheds is given in Table 5.

Depictions of the sub-shed boundaries used in the Small Tributaries TMDL model appear in Figures 3 through 26. The numbers appearing on a rectangular white background in these figures refer to the sewer-sheds included in the tributary sub-shed, using LTI's "MAPCODE" numbering system for sewer outfalls and their associated drainage sheds (LTI, 1995). ICPRB did not delineate the Watts Branch or Nash Run sub-sheds, but rather used delineations available from MWCOG.

Of the 23 streams modeled, only Piney Branch currently receives discharges from CSOs. Estimates of daily CSO discharges to Piney Branch, provided by DC WASA based on a modeling study of CSO flows conducted by LTI for the LTCP and based on 1988-90 precipitation data (private communication, Scott Rybarczyk, LTI), were used for the three-year simulation period.

Table 3. Land Use in DC Portion of Sub-Sheds

Tributary	Commercial	Federal	Forest Pervious - PG Co	Industrial	Institutional	Low-Medium Density Residential	Medium-High Density Residential	Mixed Used	Park
Battery Kemble/Fletchers Run	0	0	0	0	1	155	0	0	83
Broad Br	22	0	0	0	80	801	15	0	211
Dalecarlia Trib	41	2	0	0	95	807	0	16	150
Dumbarton Oaks	33	41	0	0	3	34	0	0	58
Fenwick Br	0	0	0	0	1	170	0	0	33
Fort Chaplin	0	0	0	0	0	135	0	0	69
Fort Davis	0	0	0	0	0	34	0	0	38
Fort Dupont	0	0	0	4	0	71	0	0	399
Fort Stanton	0	0	0	0	9	62	0	0	53
Foundry Br	22	8	0	0	19	67	0	7	45
Hickey Run	40	0	0	336	38	303	1	7	356
Klingle Valley	15	8	0	0	45	261	25	0	0
Luzon Cr	2	111	0	0	12	329	44	42	108
Melvin-Hazen Cr	0	18	0	0	21	62	28	0	55
Normanstone Cr	0	12	0	0	40	164	1	0	32
Pinehurst Br	0	0	0	0	1	294	0	0	148
Piney Br (SS only)	0	0	0	0	1	6	0	0	54
Popes Br	4	0	0	3	0	145	0	0	79
Portal Br	0	0	0	0	0	61	0	0	12
Soapstone Cr	30	31	0	0	88	281	46	5	40
Texas Ave Trib	14	0	0	0	0	113	0	0	48

Table 4. Tributary Sub-Shed Estimates of Pervious and Impervious Surface

Name	TotalArea (ac)	Impervious Area (ac)	Urban Pervious Area (ac)
Battery Kemble/Fletchers Run	239	42	197
Broad Br	1129	281	849
Dalecarlia Trib	1111	306	805
Dumbarton Oaks	168	61	106
Fort Dupont	474	49	425
Foundry Br	168	58	110
Fort Chaplin	204	35	168
Fort Davis	72	10	61
Fenwick Br	203	41	162
Fort Stanton	125	25	100
Hickey Run	1081	409	672
Klingle Valley	354	123	231
Luzon Cr	648	217	431
Melvin-Hazen Cr	184	61	123
Nash Run	465	163	302
Normanstone Cr	249	77	172
Popes Br	232	44	188
Pinehurst Br	443	78	365
Portal Br	73	15	58
Piney Br (SS only)	61	6	55
Soapstone Cr	520	203	317
Texas Ave Trib	176	39	137
Watts Br	2470	821	1425

Table 5. District and Maryland Portions of Sub-shed Areas

Tributary	Total Area (ac)	DC Area (ac)	DC Area (% of Total)	MD Area (ac)	MD Area (% of Total)
Battery Kemble/Fletchers Run	239	239	100.00%	0	0.00%
Broad Br	1129	1129	100.00%	0	0.00%
Dalecarlia Trib	1142	1111	97.29%	31	2.71%
Dumbarton Oaks	168	168	100.00%	0	0.00%
Fenwick Br	612	205	33.50%	407	66.50%
Fort Chaplin	204	204	100.00%	0	0.00%
Fort Davis	72	72	100.00%	0	0.00%
Fort Dupont	474	474	100.00%	0	0.00%
Fort Stanton	125	125	100.00%	0	0.00%
Foundry Br	168	168	100.00%	0	0.00%
Hickey Run	1081	1081	100.00%	0	0.00%
Klingle Valley	354	354	100.00%	0	0.00%
Luzon Cr	648	648	100.00%	0	0.00%
Melvin-Hazen Cr	184	184	100.00%	0	0.00%
Nash Run	465	286	61.51%	179	38.49%
Normanstone Cr	249	249	100.00%	0	0.00%
Pinehurst Br	619	434	70.11%	185	29.89%
Piney Br	61	61	100.00%	0	0.00%
Popes Br	232	232	100.00%	0	0.00%
Portal Br	213	75	35.21%	139	65.26%
Soapstone Cr	520	520	100.00%	0	0.00%
Texas Ave Trib	176	176	100.00%	0	0.00%
Watts Br	2405	1121	46.61%	1284	53.39%

II.3. Daily Concentration Estimates

The DC Small Tributaries TMDL Model uses the assumption that on each day of the simulation period a volume of base flow and a volume of storm flow water discharges into each tributary and completely mixes. For a given constituent, all tributary base flow volumes and storm flow volumes are assumed to have the estimated base flow concentrations and storm flow concentrations given in Tables 2a, 2b, or 2c.

Model estimates of daily base flow and storm flow volumes discharging into each tributary are obtained as follows:

$$\text{BaseFlow} = \alpha_1 * (\text{PervArea} * \text{PerviousBase} + \text{ForPervArea} * \text{ForestBase}) \quad \textbf{(1)}$$

$$\text{StormFlow} = \alpha_1 * (\text{ImpArea} * \text{ImperviousStorm} + \text{PervArea} * \text{PerviousStorm} + \text{ForPervArea} * \text{ForestStorm}) \quad \textbf{(2)}$$

where

BaseFlow	= base flow entering tributary (m^3/sec)
StormFlow	= storm flow entering tributary (m^3/sec)
PerviousBase	= base flow per unit urban pervious area from Watts Br HSPF model (ac-in/ac-hr)
ForestBase	= base flow per unit forested area from Watts Br HSPF model (ac-in/ac-hr)
ImperviousStorm	= storm flow per unit impervious area from Watts Br HSPF model (ac-in/ac-hr)
PerviousStorm	= storm flow per unit urban pervious area from Watts Br HSPF model (ac-in/ac-hr)
ForestStorm	= storm flow per unit forested area from Watts Br HSPF model (ac-in/ac-hr)
PervArea	= urban pervious area of tributary sub-shed (ac)
ImpArea	= impervious area of tributary sub-shed (ac)
ForPervArea	= forested pervious area of tributary sub-shed (ac)
α_1	= 0.02855 = conversion factor from (ac-in/hr) to (m^3/sec)

Daily constituent concentrations for each tributary with the exception of Piney Branch are then predicted using the following:

$$C = (\text{BaseFlow} * \text{BFConc} + \text{StormFlow} * \text{SFConc}) * \text{LoadMult} \,/\, (\text{BaseFlow} + \text{StormFlow}) \quad \textbf{(3)}$$

where

C	= model estimate of total constituent concentration (dissolved + particulate) in tributary
BFConc	= constituent baseflow concentration (dissolved + particulate)
SFConc	= constituent stormflow concentration (dissolved + particulate)
LoadMult	= load multiplier for simulating effect of potential load reduction scenarios from the District's separate sewer system

and where C, BFConc, and SFConc are in consistent units. For the Piney Branch tributary, the effect of loads from combined sewer system overflows (CSOs) is included. Daily volumes of CSO discharge to Piney Branch for the three-year time period, 1988-90 were provided by WASA (Scott Rybarzyck, private communication). Constituent concentration in Piney Branch were predicted using the following:

$$C = (\text{BaseFlow} * \text{BFConc} * \text{LoadMult} + \text{StormFlow} * \text{SFConc} * \text{LoadMult} + \text{CSOFlow} * \text{CSOConc} * \text{LoadMultCSO}) \,/\, (\text{BaseFlow} + \text{StormFlow} + \text{CSOFlow}) \qquad \textbf{(4)}$$

where

CSOConc	= constituent concentration in CSOs (dissolved + particulate)
CSOFlow	= CSO flow for Piney Branch in m^3/sec
LoadMultCSO	= load multiplier for evaluating effect of potential load reduction scenarios from the CSOs

Finally, the total daily load for each constituent for each tributary is calculated by

$$\text{Load} = \alpha_2 * (\text{BaseFlow} * \text{BFConc} * \text{LoadMult} + \text{StormFlow} * \text{SFConc} * \text{LoadMult} + \text{CSOFlow} * \text{CSOConc} * \text{LoadMultCSO}) \qquad \textbf{(5)}$$

where

α_2	= 0.0864 = conversion factor from (g/sec) to (kg/day)

II.4. Calculation of Dissolved Inorganics Concentrations

District of Columbia Water Quality Standards for the inorganic chemicals modeled (Table 2b) are given in terms of the dissolved fraction of these constituents. Therefore, in order to compare predictions of the inorganic chemicals sub-model with WQS, daily predictions for total zinc, lead, copper and arsenic are used to compute daily predictions for the dissolved fractions of these constituents using the assumption of instantaneous equilibrium partitioning, where the partitioning between the solid phase and the dissolved phase is assumed to be linear (Karickhoff, 1984), that is,

$$C_s = K_d\, C_w \tag{6}$$

where the total constituent concentration is given by

$$C = C_w + C'_s \tag{7}$$

with

$$C'_s = C_s\, TSS \tag{8}$$

and

C_s	=	concentration of contaminant on solid phase (µg/g)
C'_s	=	concentration of contaminant on solid phase (µg/L)
C_w	=	concentration of contaminant in dissolved phase (µg/L)
TSS	=	concentration of total suspended solids (g/L)
K_d	=	partition coefficient (L/g)

Thus, combining equations (6), (7), and (8), the dissolved phase concentration, C_w, can be expressed in terms of the total concentration, C, as

$$C_w = C/(1 + TSS\, K_d) \tag{9}$$

Equation (9) is used in the DC Small Tributaries TMDL sub-model for inorganics to convert the model's daily predictions of total zinc, lead, copper, and arsenic concentrations to predictions of corresponding dissolved concentrations.

Because very little concentration data are available for the 23 tributaries with both dissolved and solid phase values, partition coefficients were taken from the District's TMDL model for toxics in the Anacostia River, the TAM/WASP Toxics Screening Level Model. Values for TSS in equation (9) are obtained from model predictions of daily TSS values using equations (1) through (4), and assuming base flow, storm flow, and CSO TSS concentrations of 0.002, 0.094, and 0.171 g/L, respectively, also taken from the TAM/WASP model.

Table 6. K_d Values Used in the DC Small Tributaries TMDL Model

Constituent	K_d [1] (L/g)
Zinc	420
Lead	400
Copper	94
Arsenic	100

[1] From Behm et al., 2003.

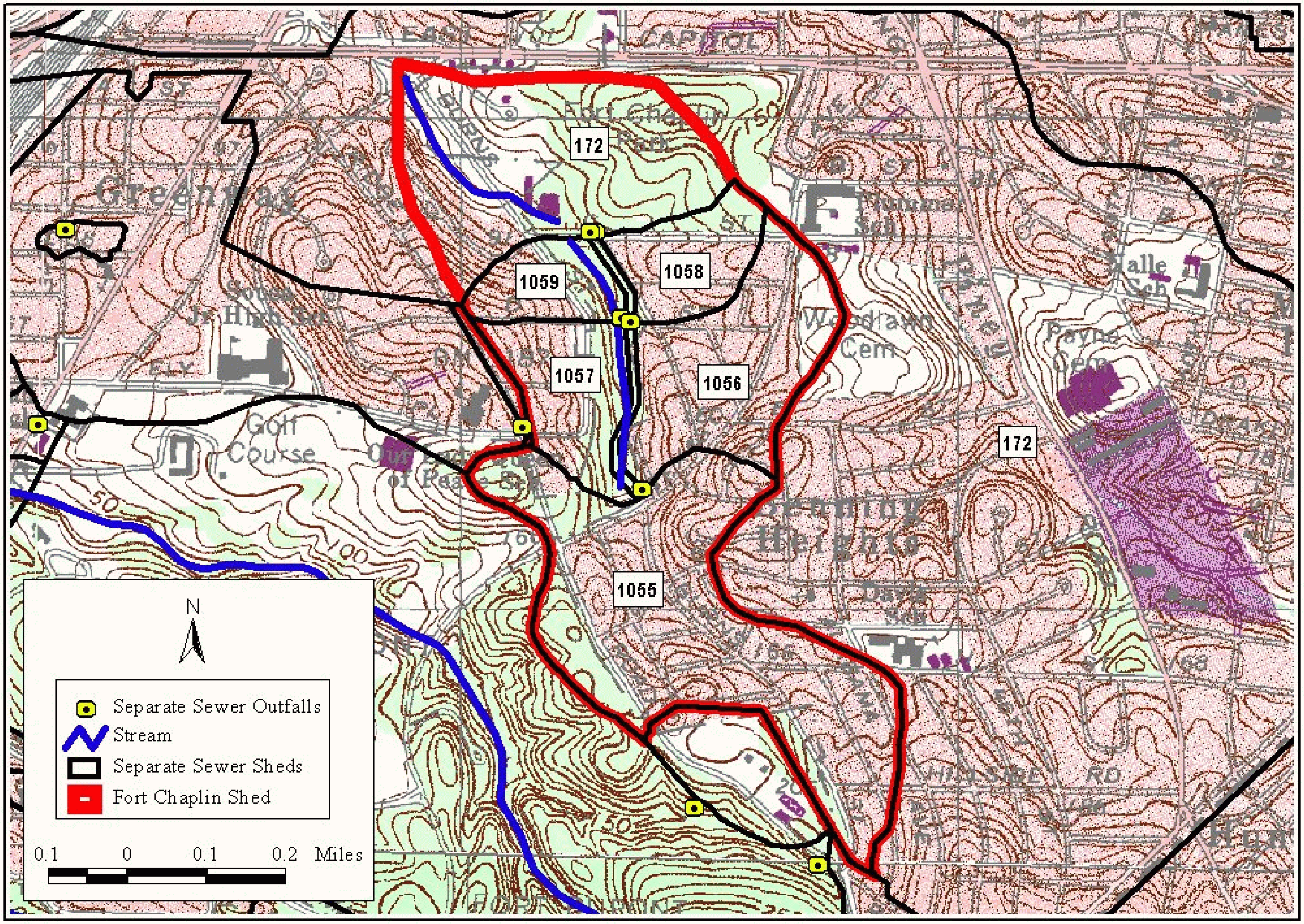

Figure 3. Fort Chaplin Sub-Shed

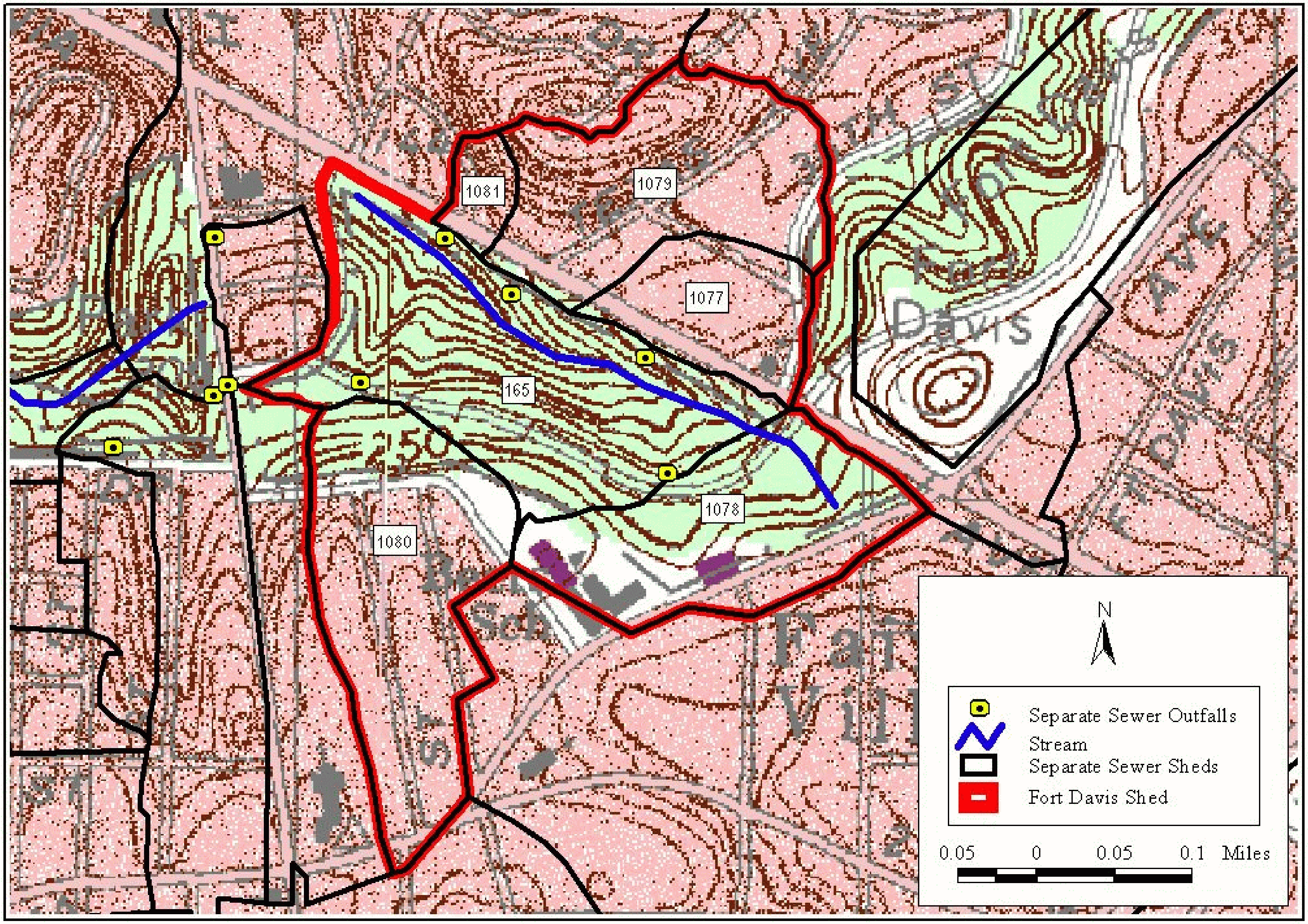

Figure 4. Fort Davis Sub-Shed

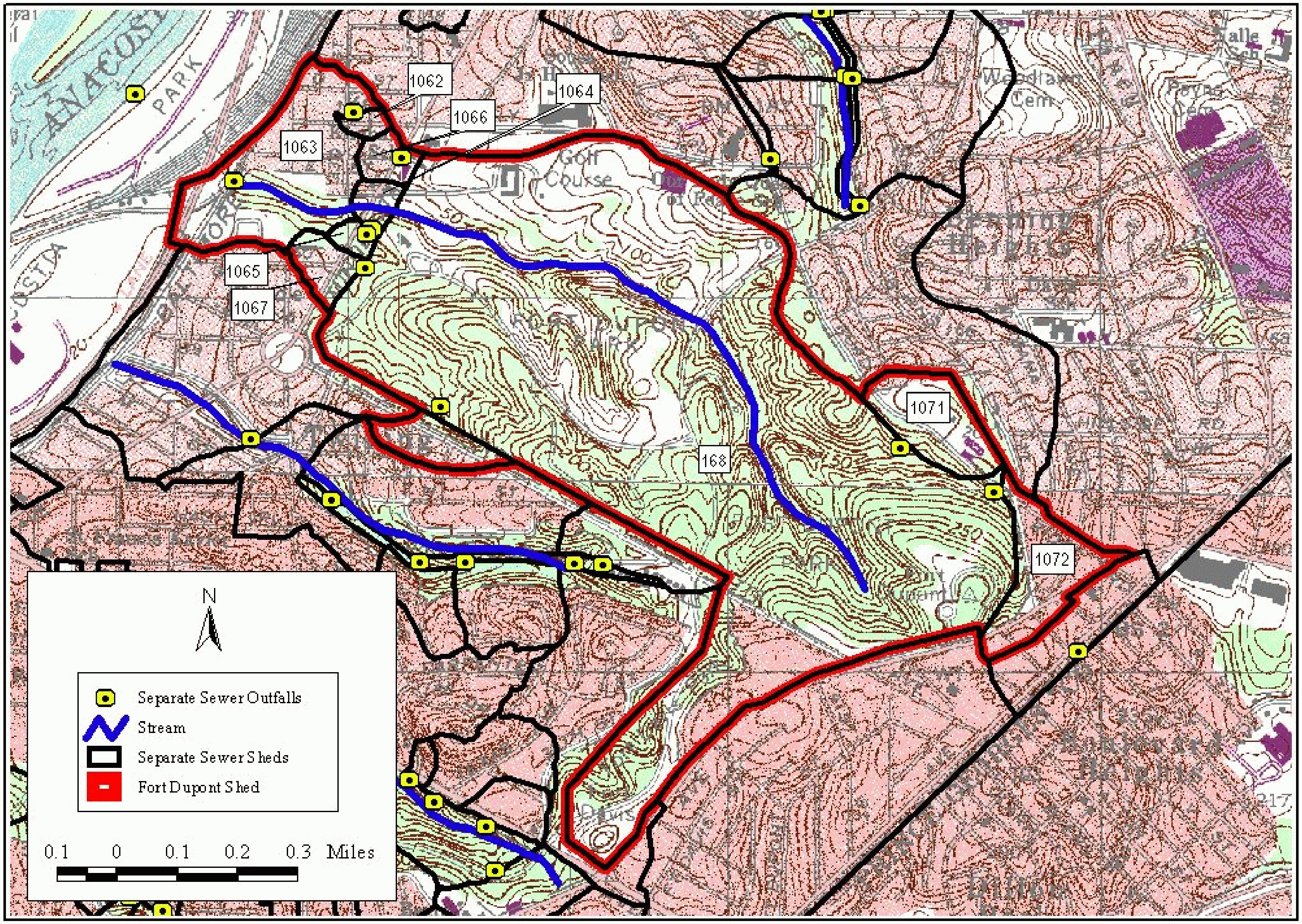

Figure 5. Fort Dupont Sub-Shed

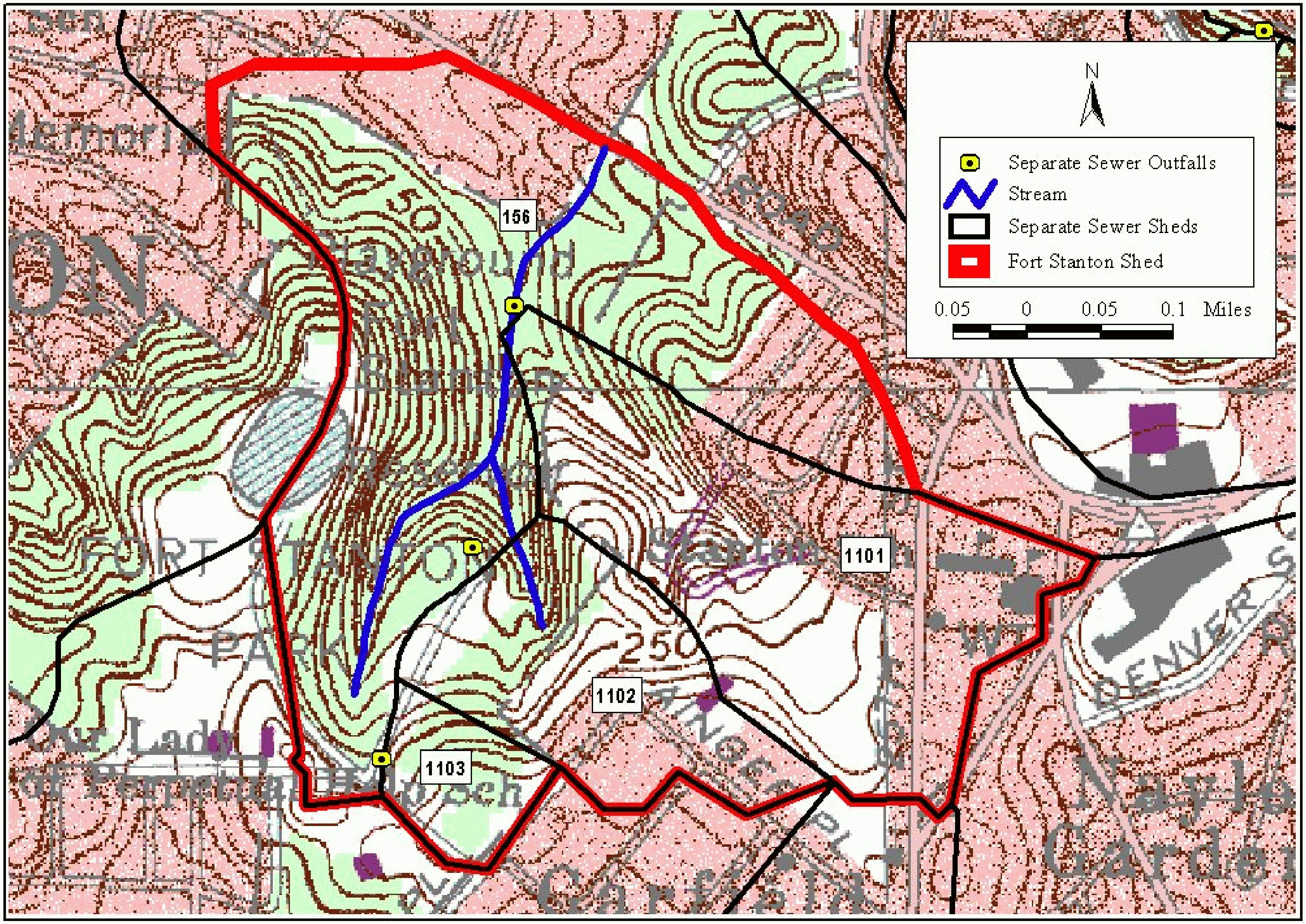

Figure 6. Fort Stanton Sub-Shed

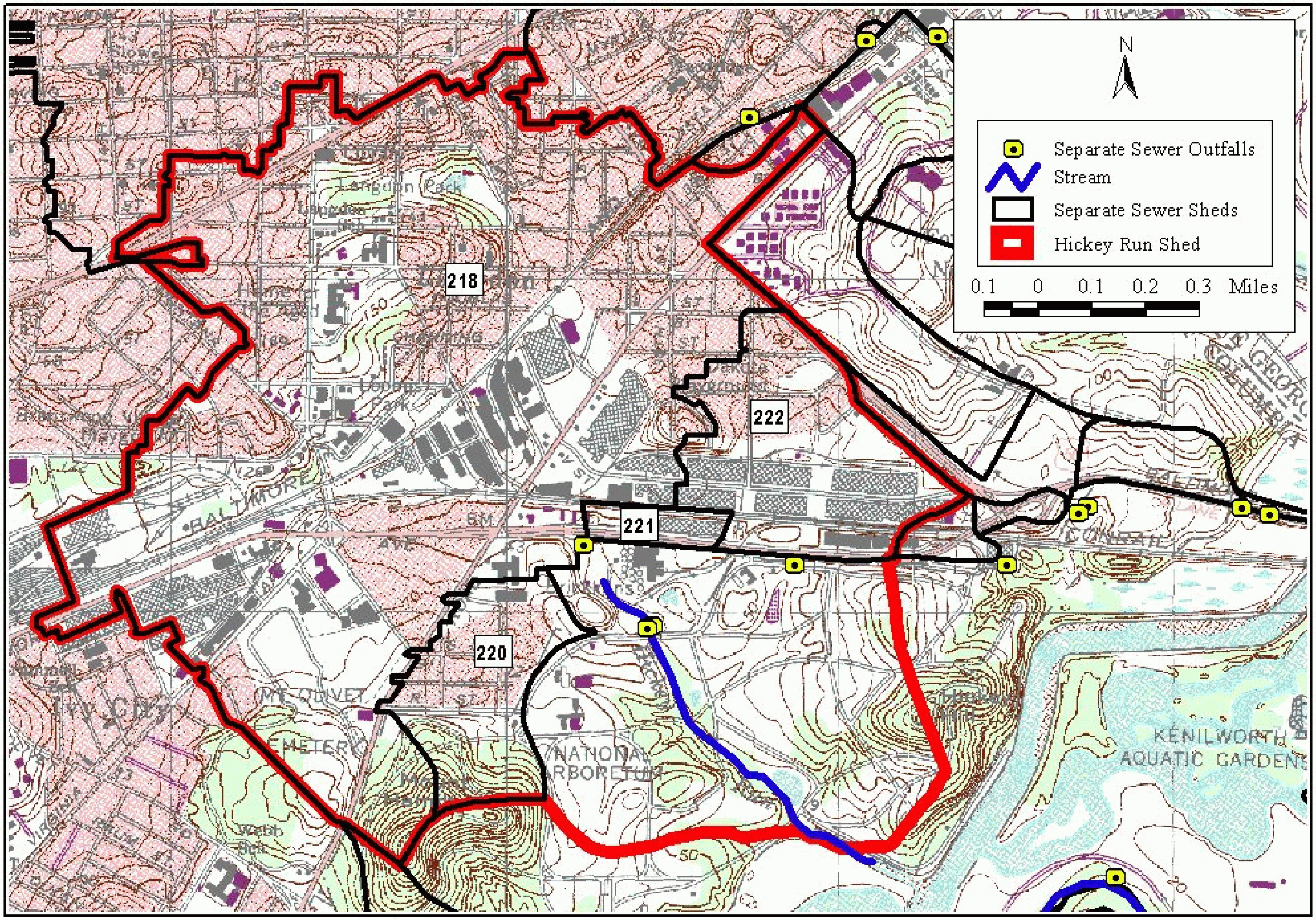

Figure 7. Hickey Run Sub-Shed

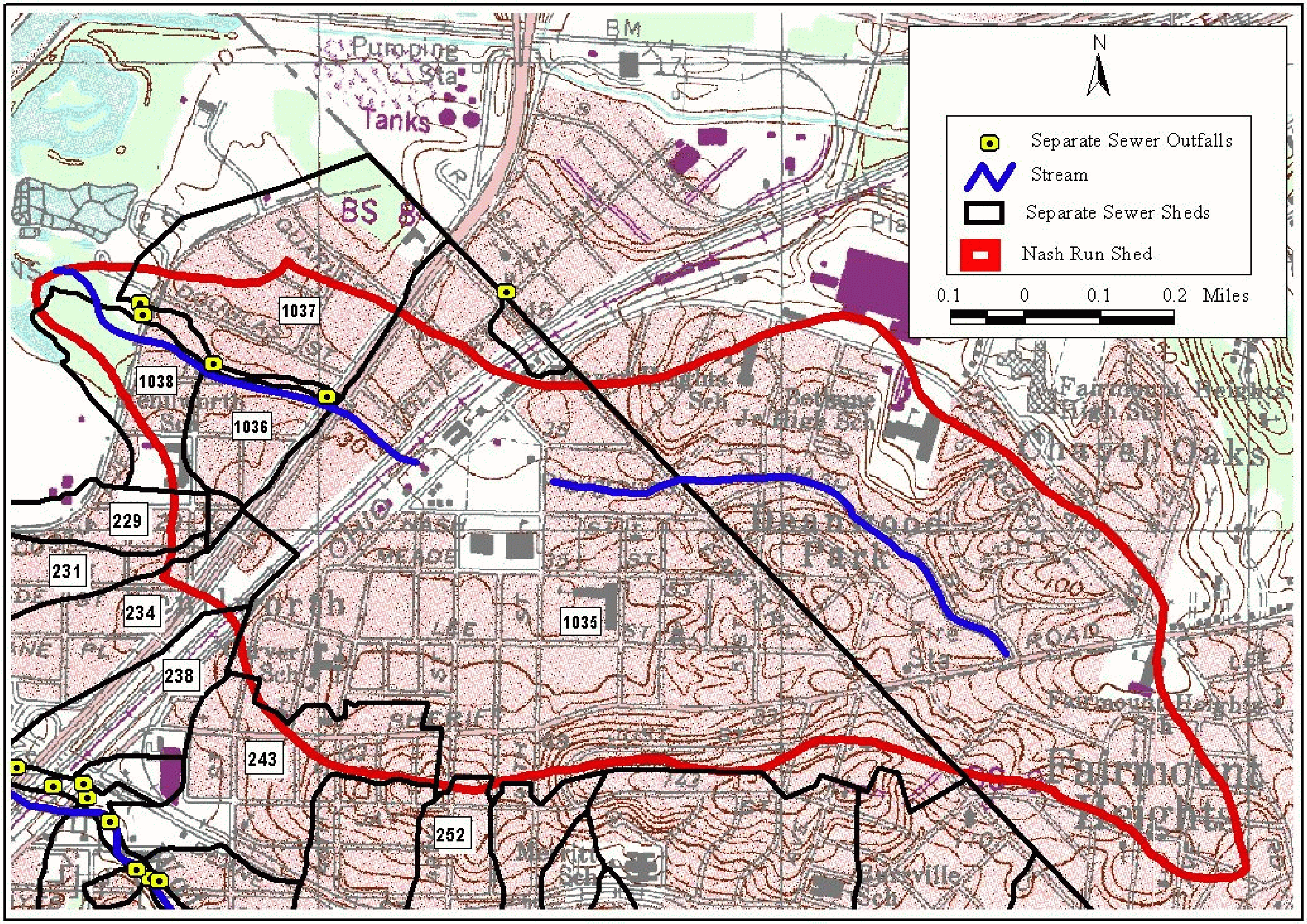

Figure 8. Nash Run Sub-Shed

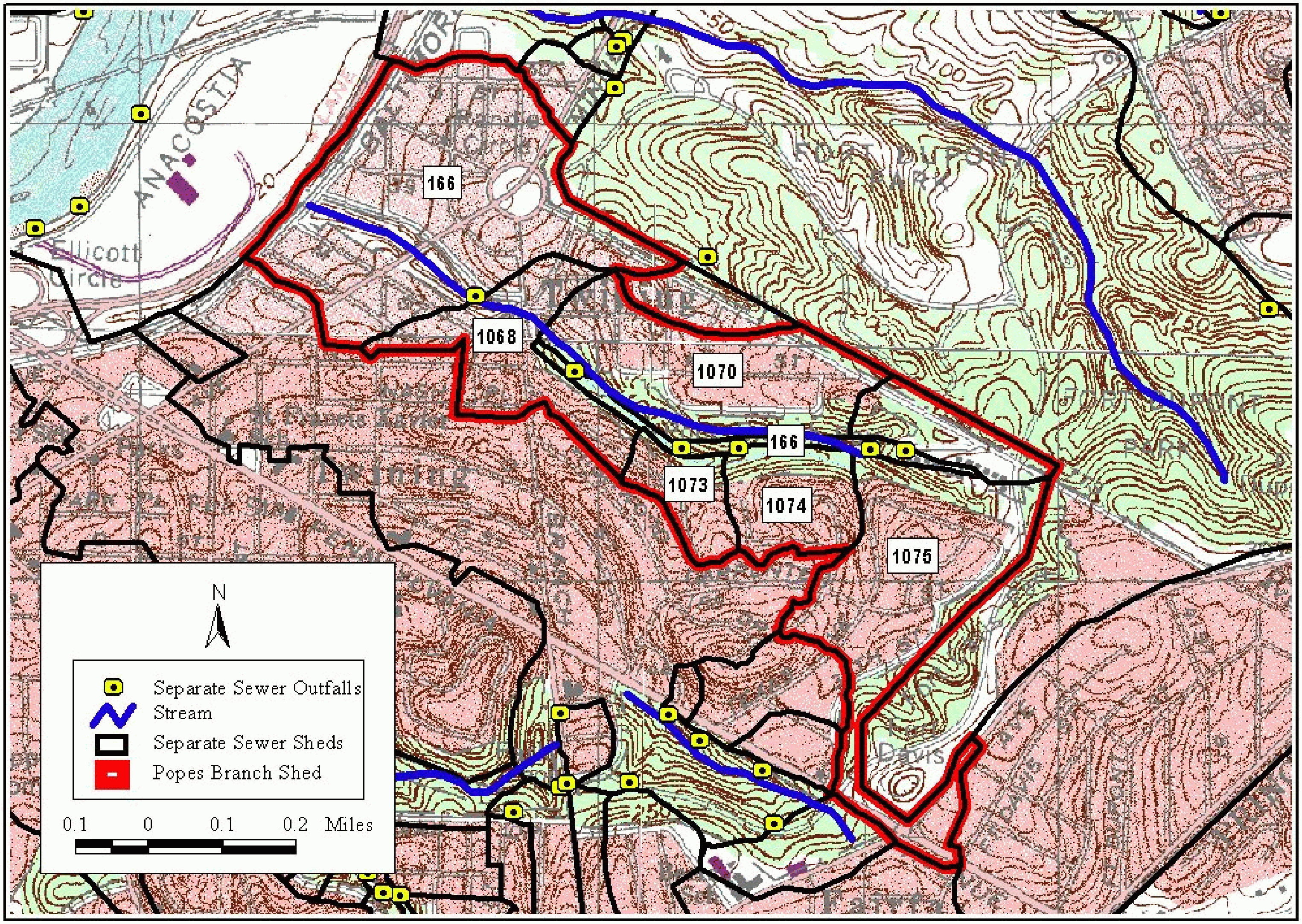

Figure 9. Popes Branch Sub-Shed

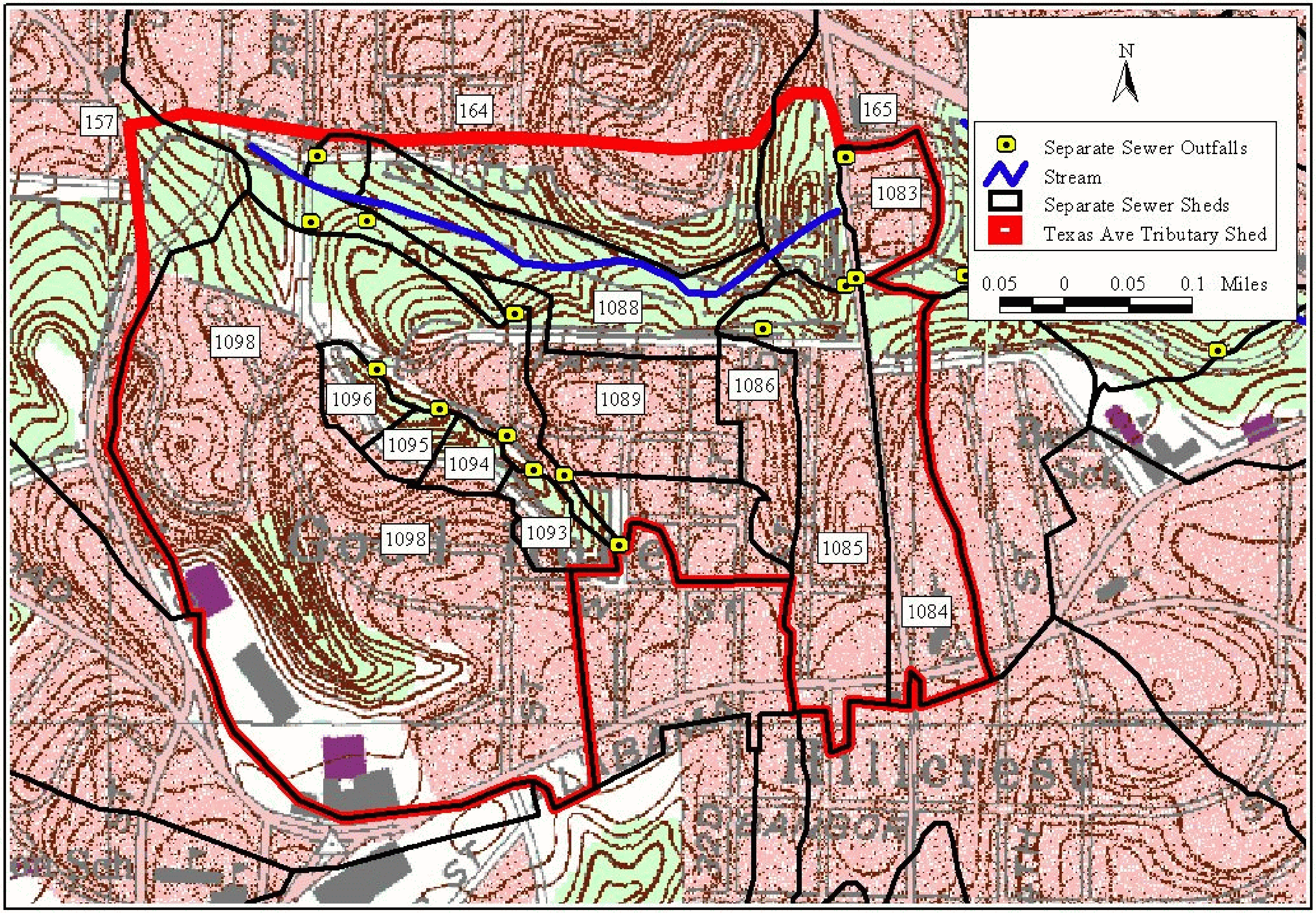

Figure 10. Texas Avenue Tributary Sub-Shed

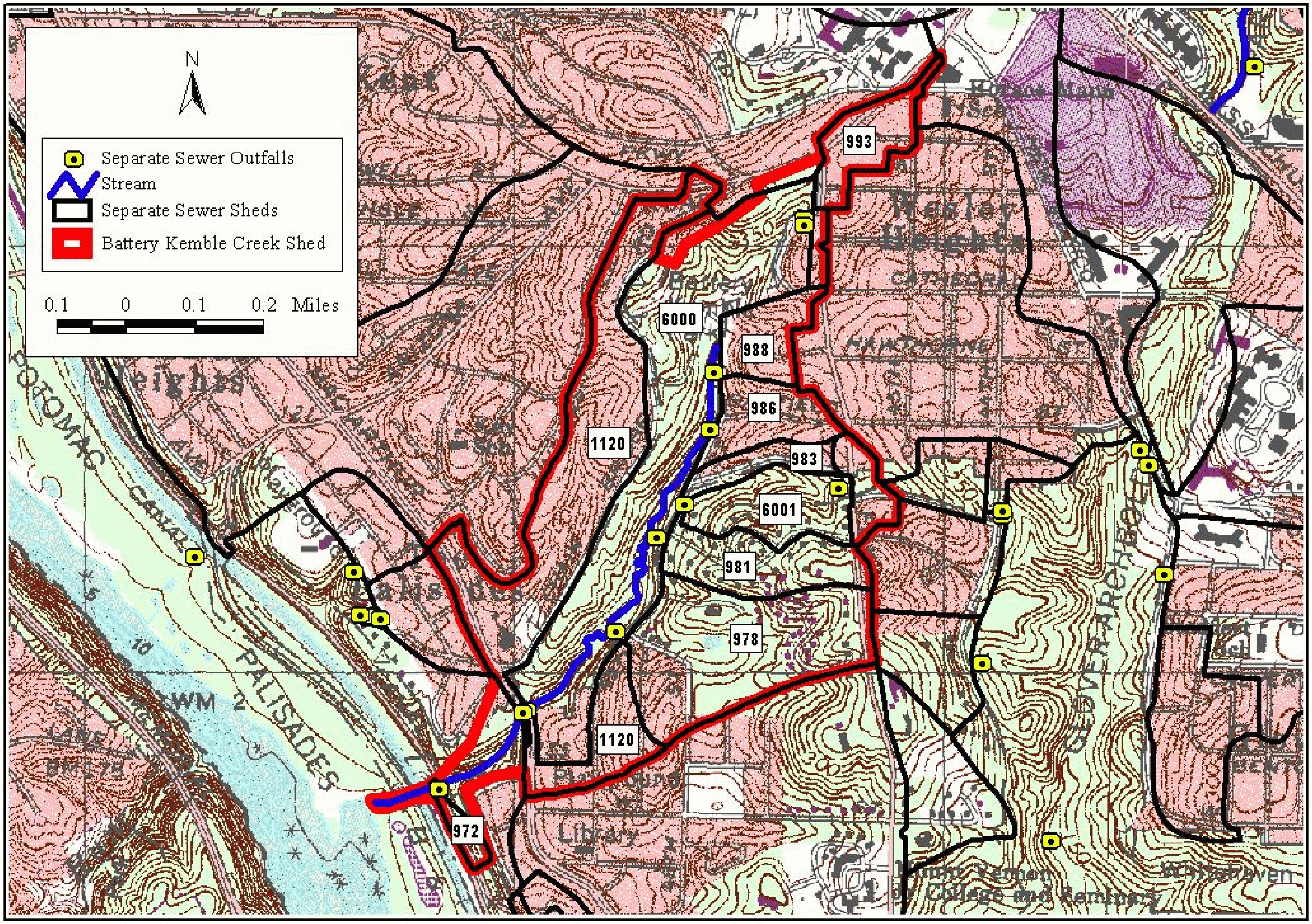

Figure 11. Battery Kemble/Fletchers Run Sub-Shed

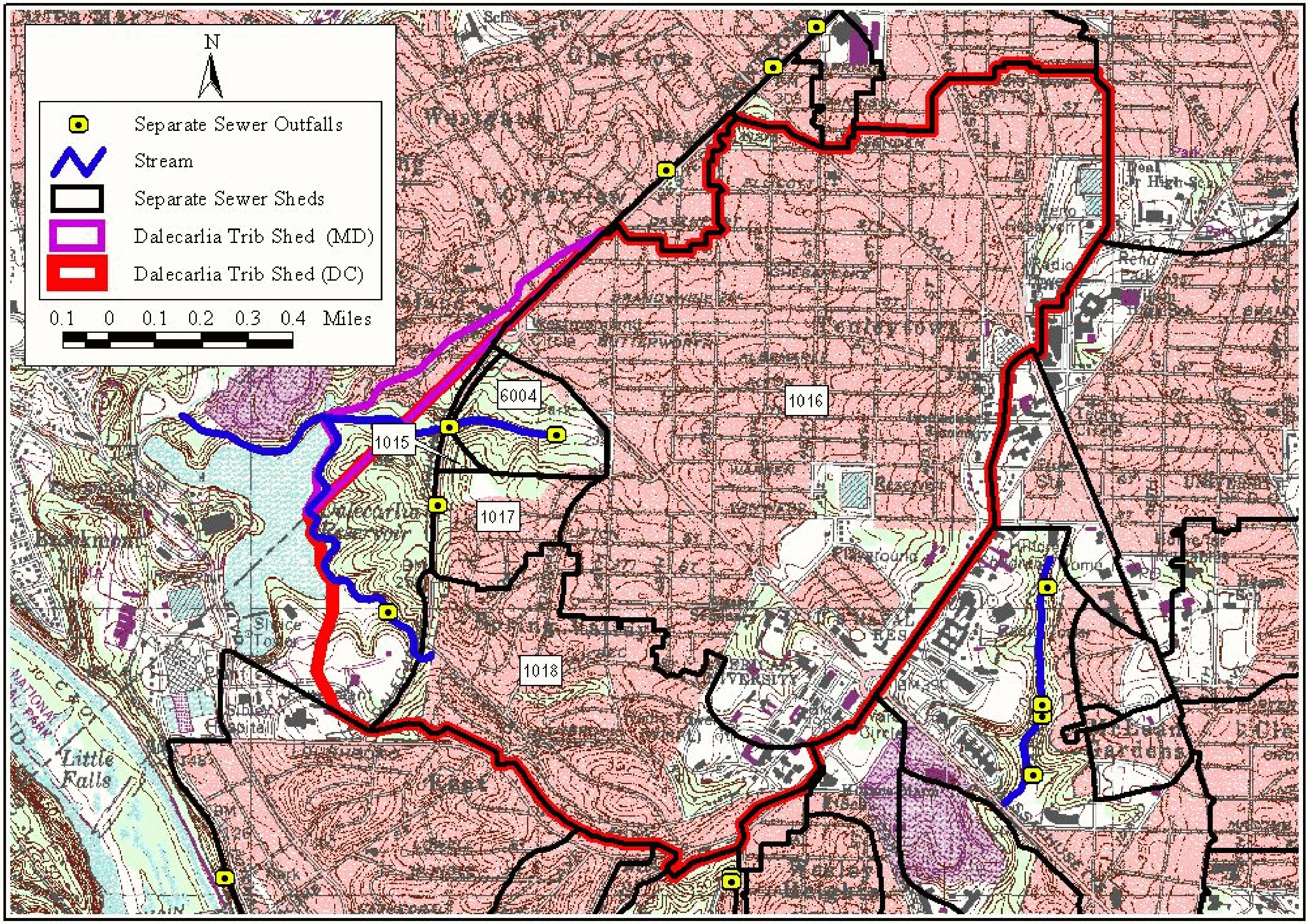

Figure 12. Dalecarlia Tributary Sub-Shed

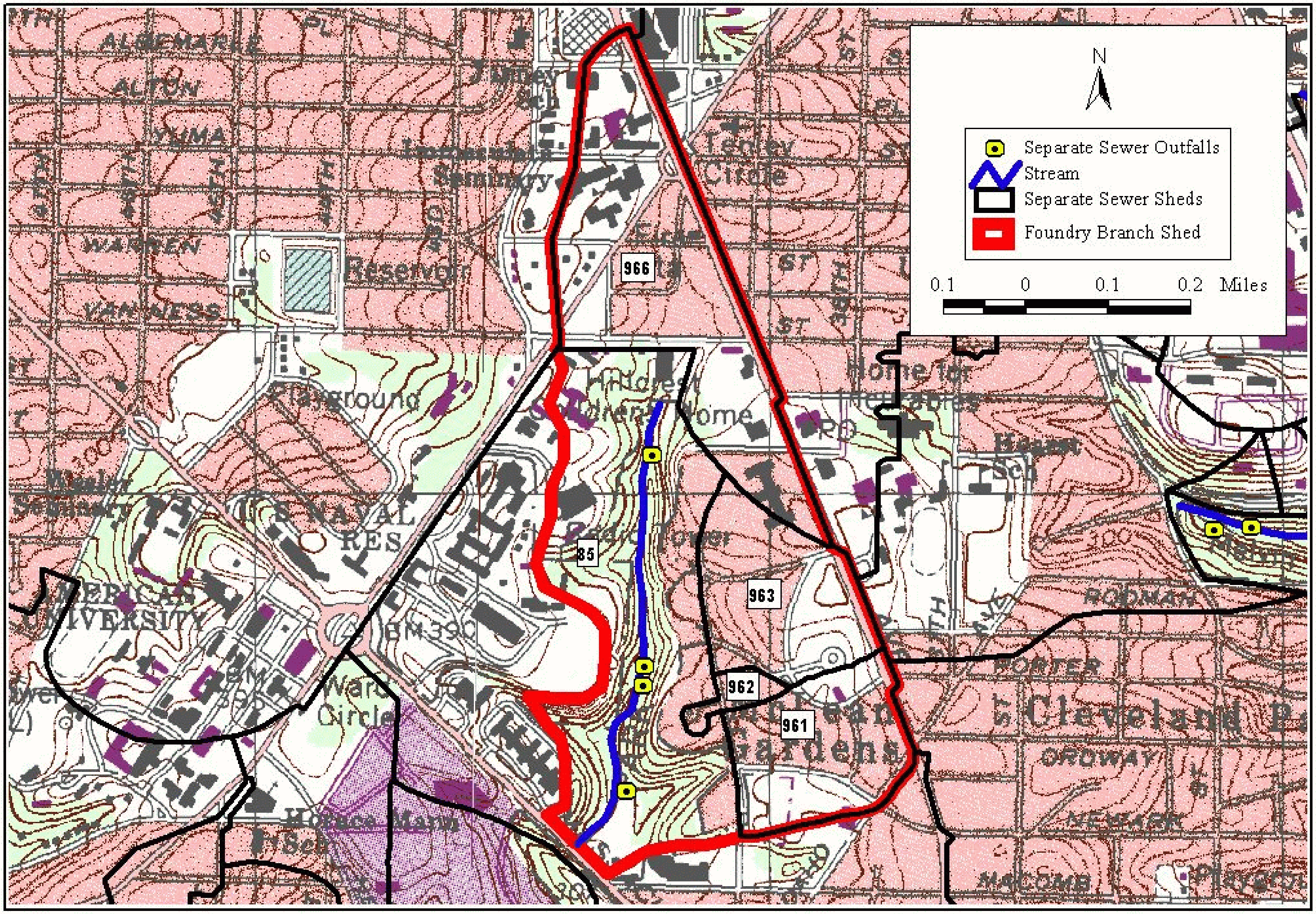

Figure 13. Foundry Branch Sub-Shed

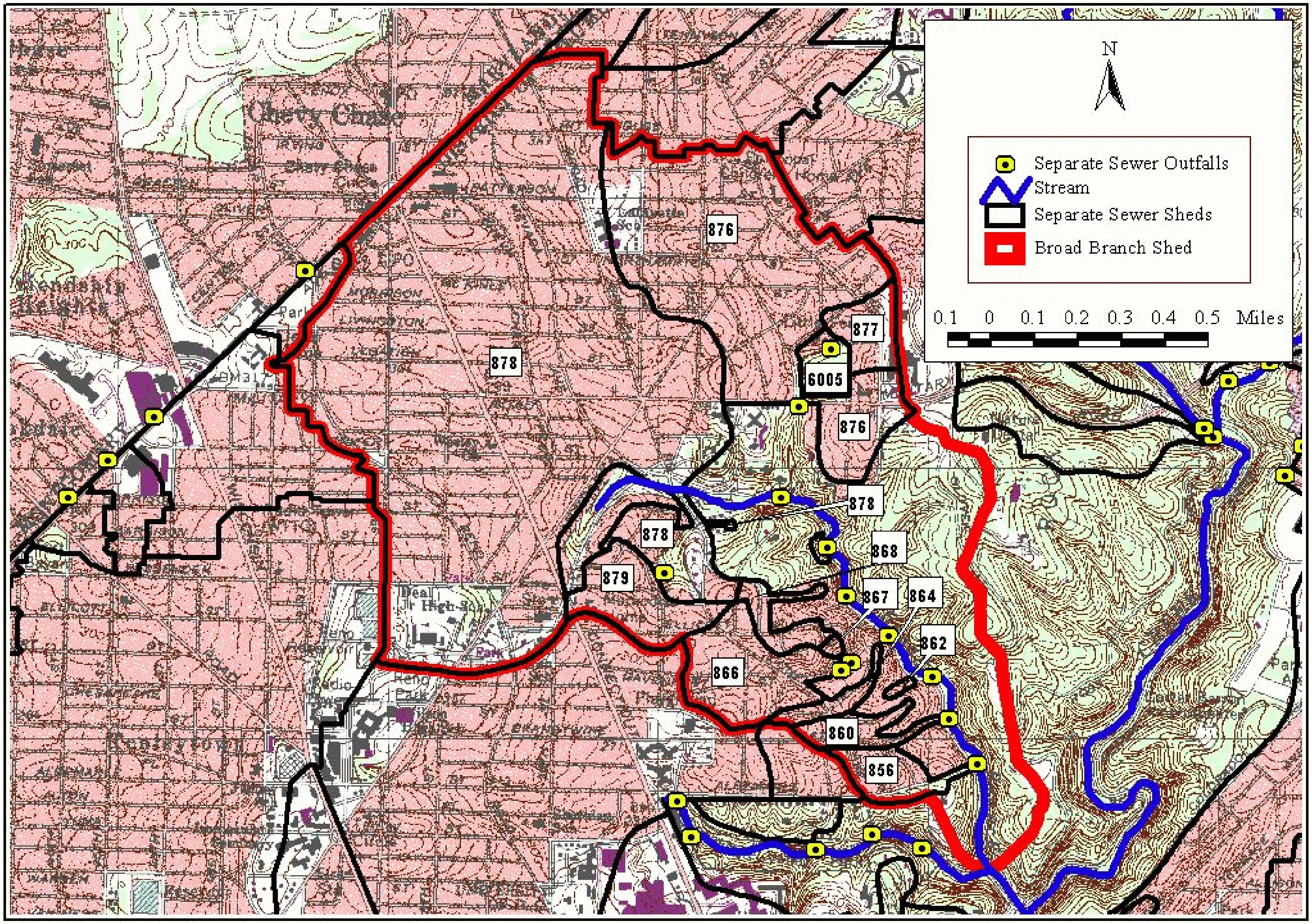

Figure 14. Broad Branch Sub-Shed

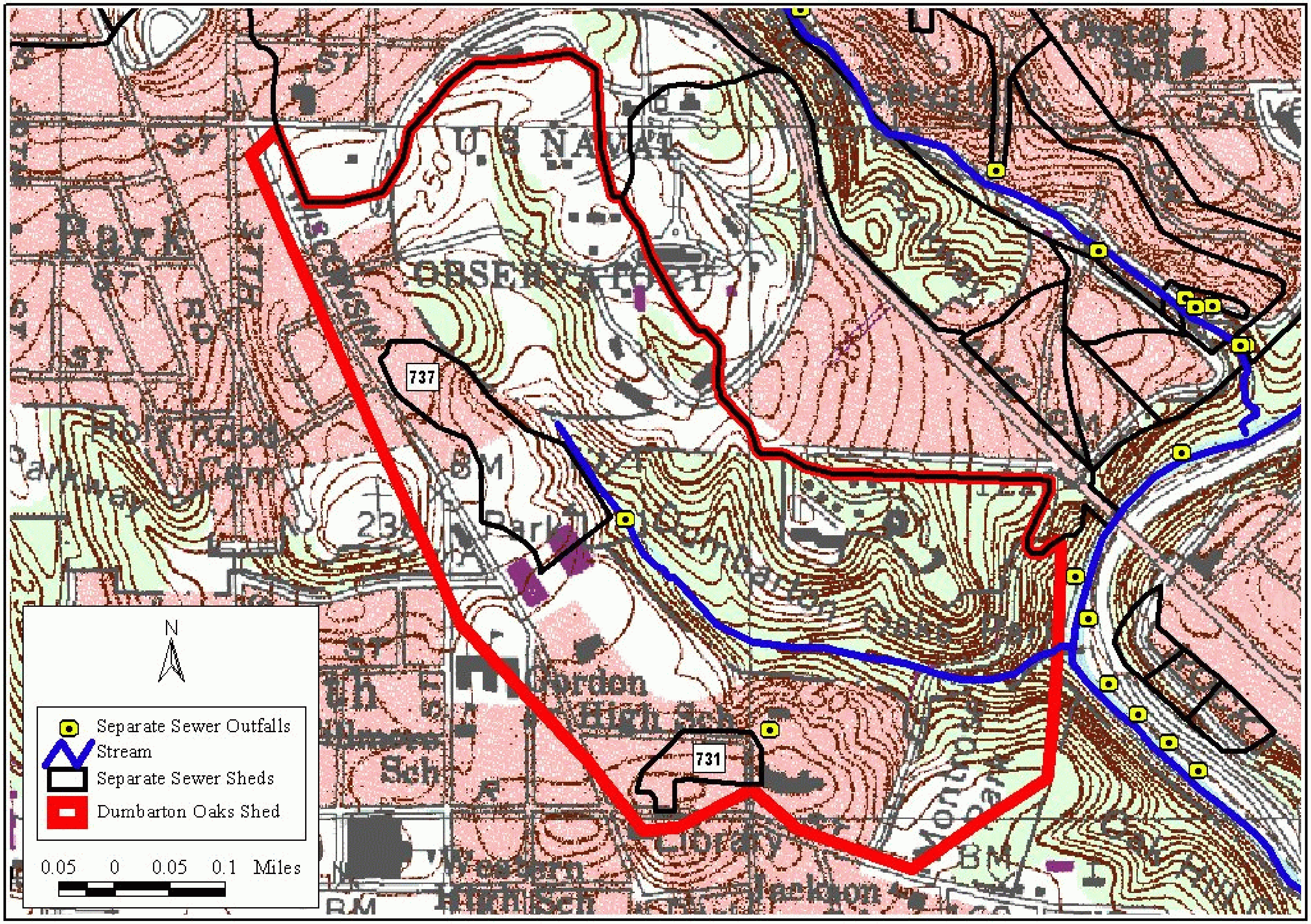

Figure 15. Dumbarton Oaks Sub-Shed

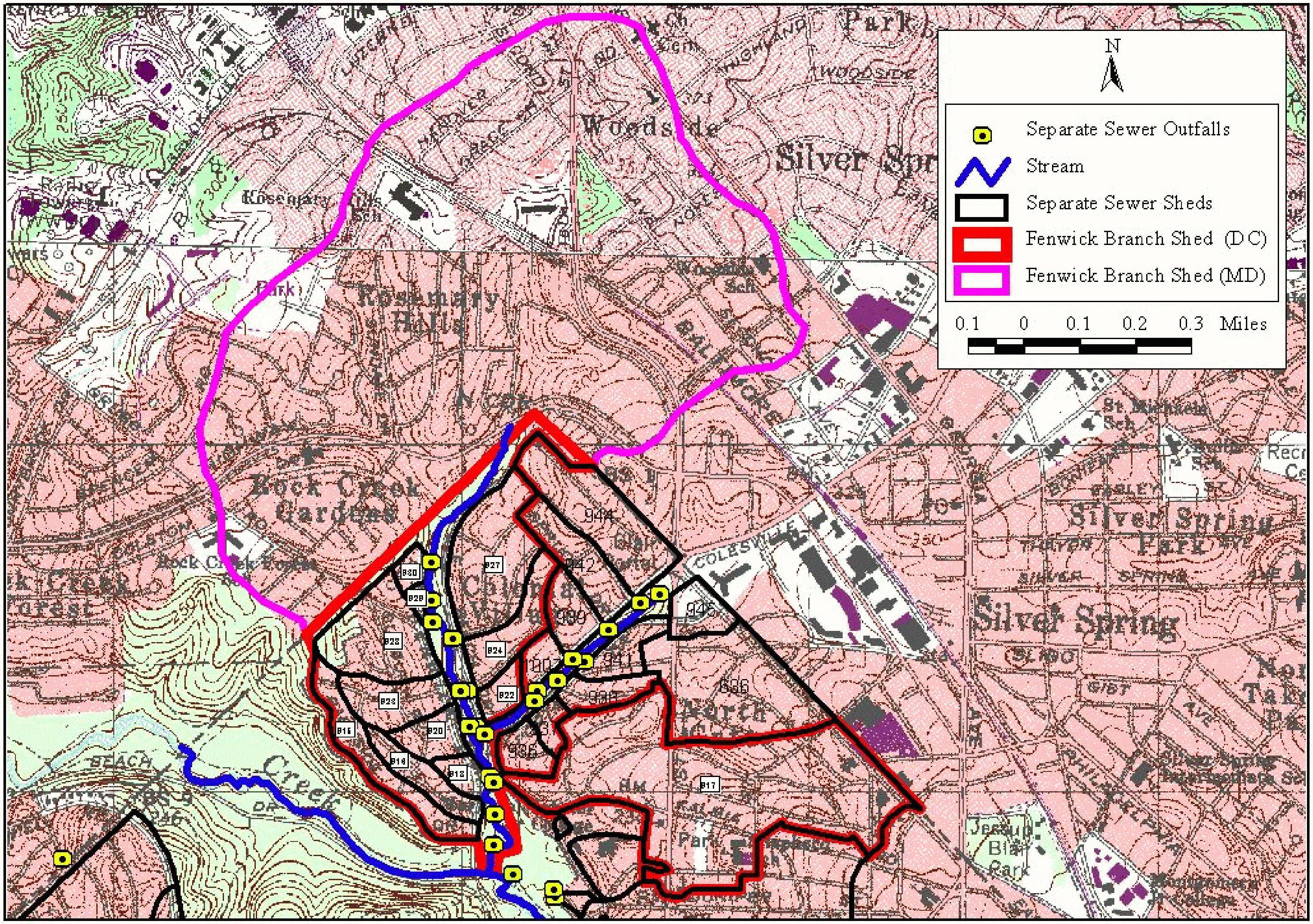

Figure 16. Fenwick Branch Sub-Shed

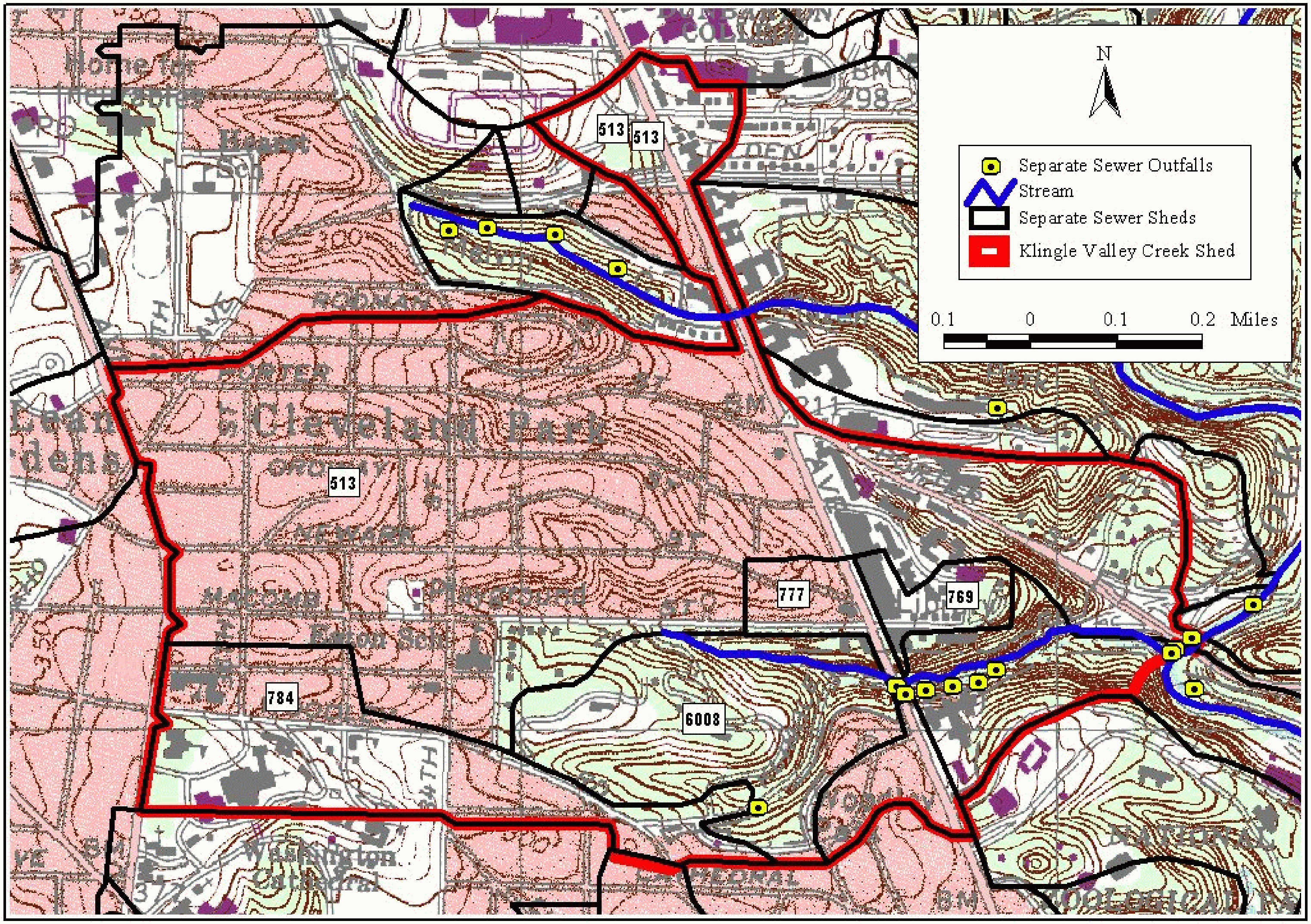

Figure 17. Klingle Valley Sub-Shed

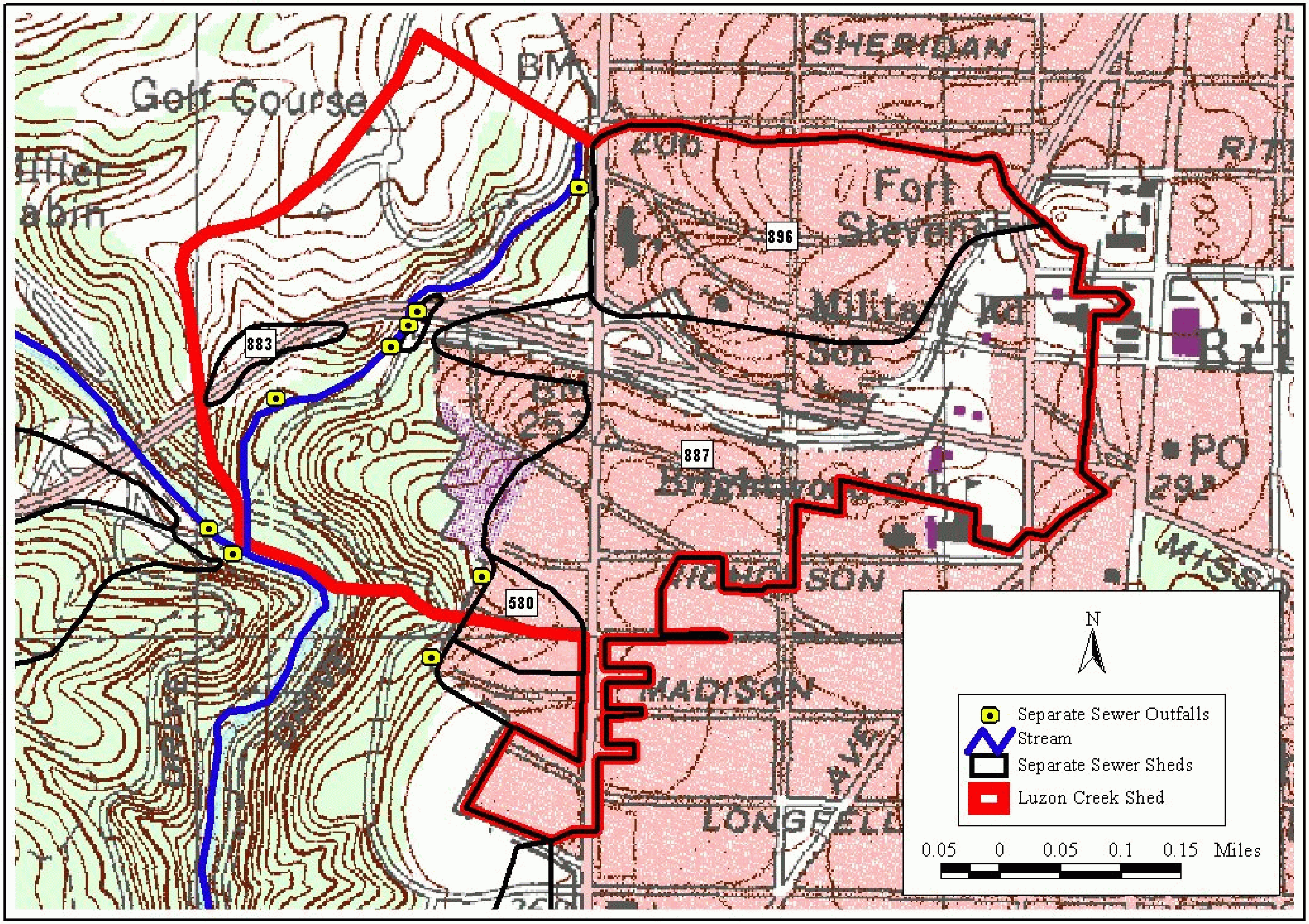

Figure 18. Luzon Branch Sub-Shed

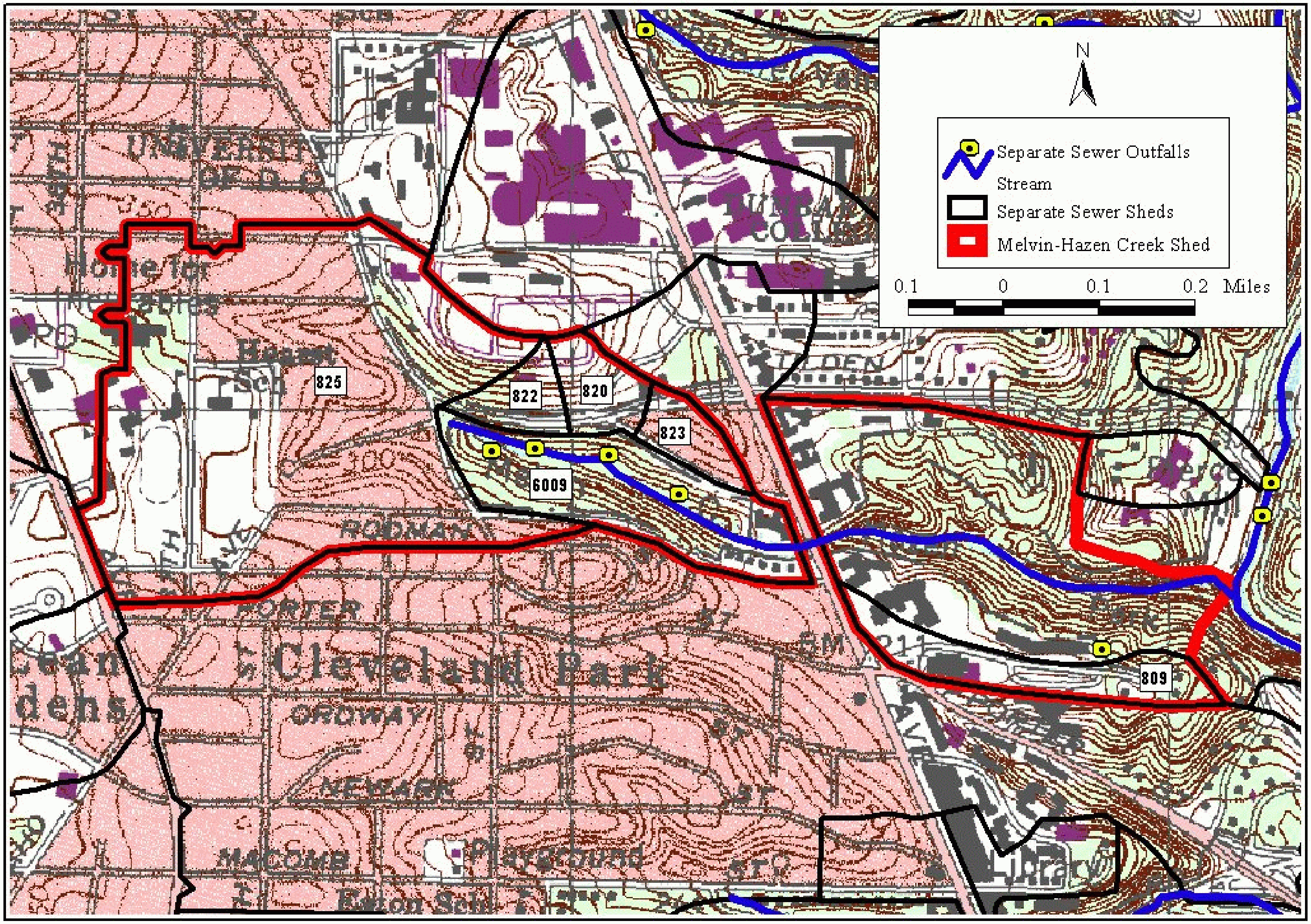

Figure 19. Melvin-Hazen Valley Sub-Shed

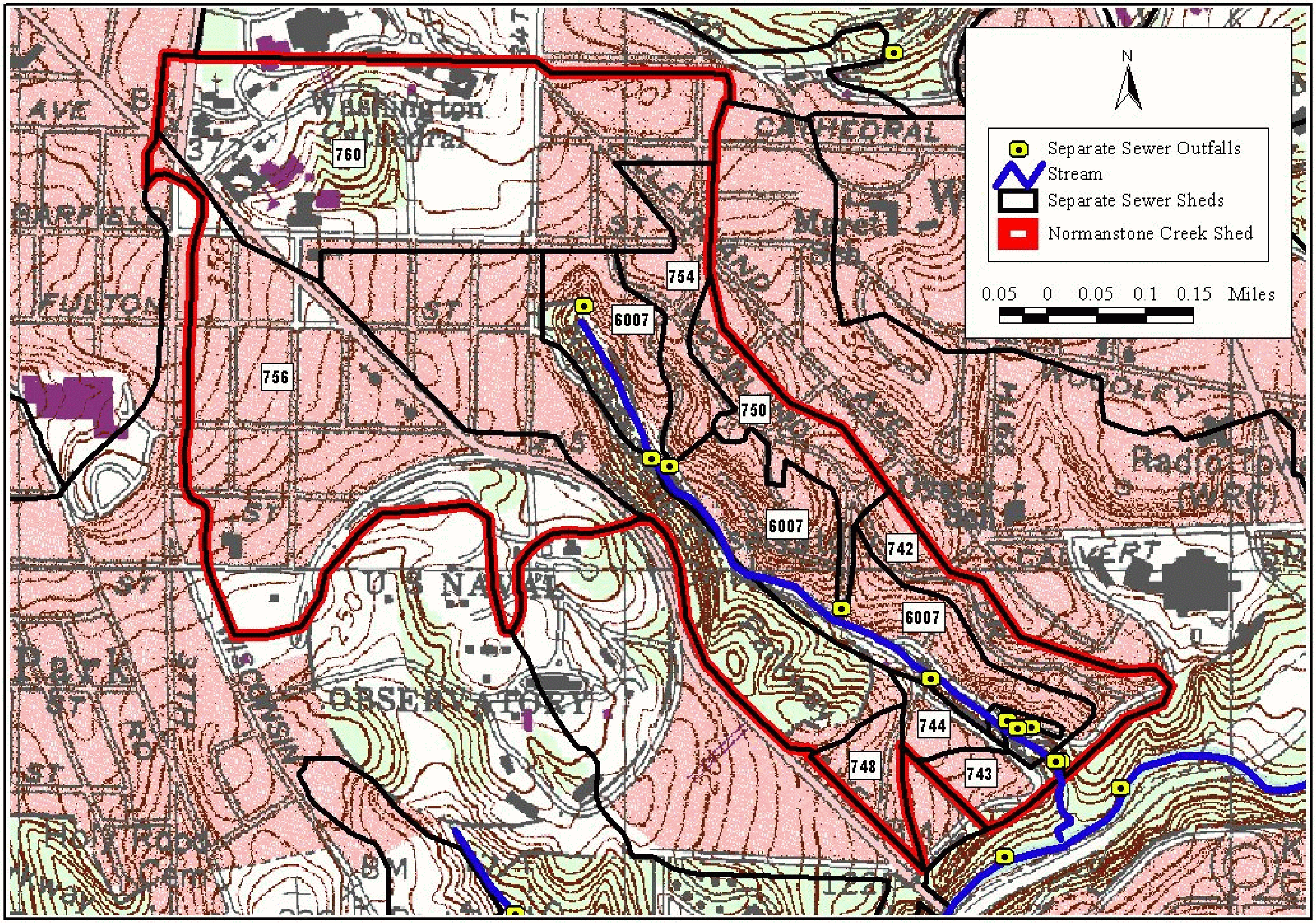

Figure 20. Normanstone Creek Sub-Shed

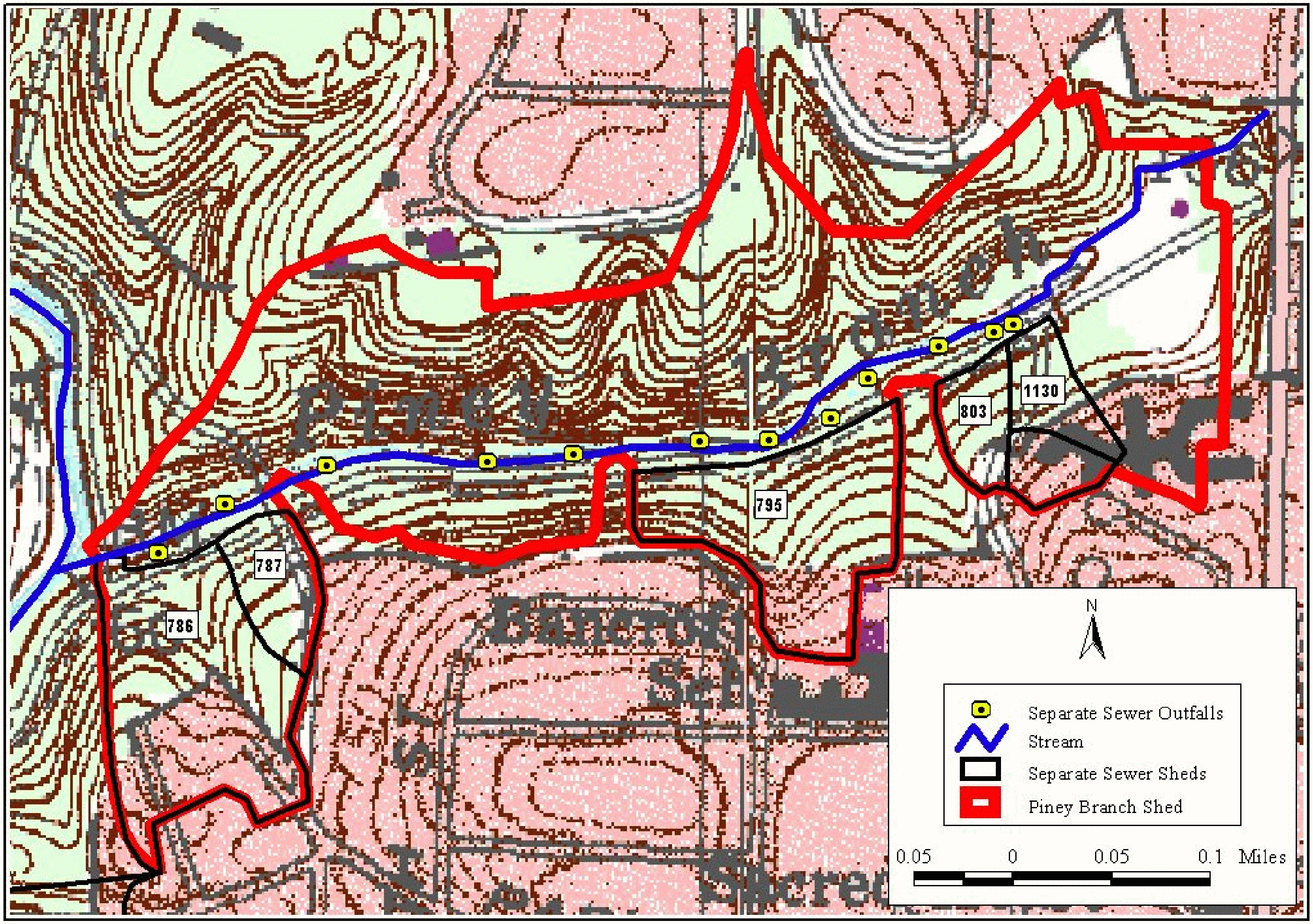

Figure 21. Separate Sewer and Direct Drainage Portion of Piney Branch Sub-Shed

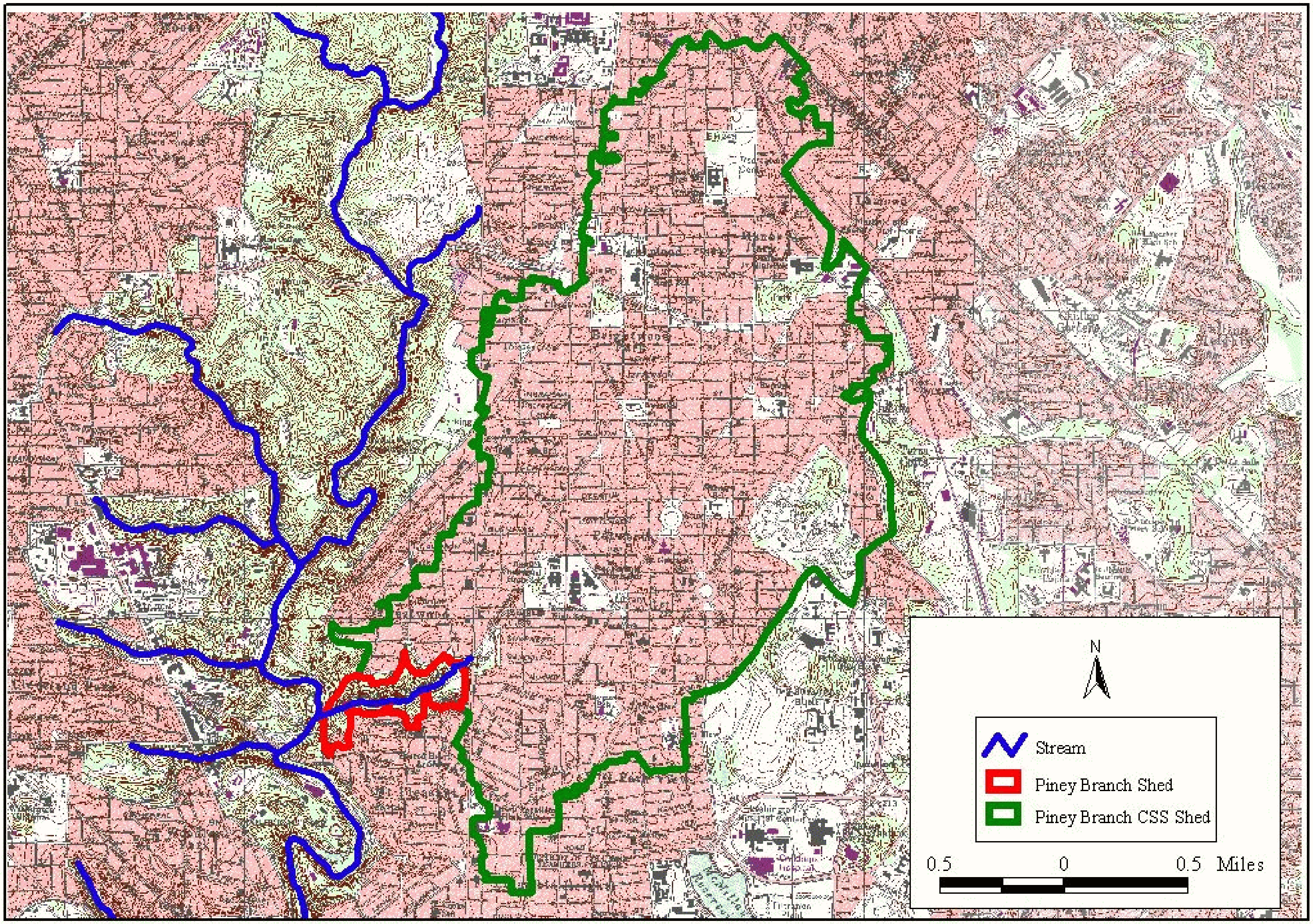

Figure 22. CSO Portion of Piney Branch Sub-Shed

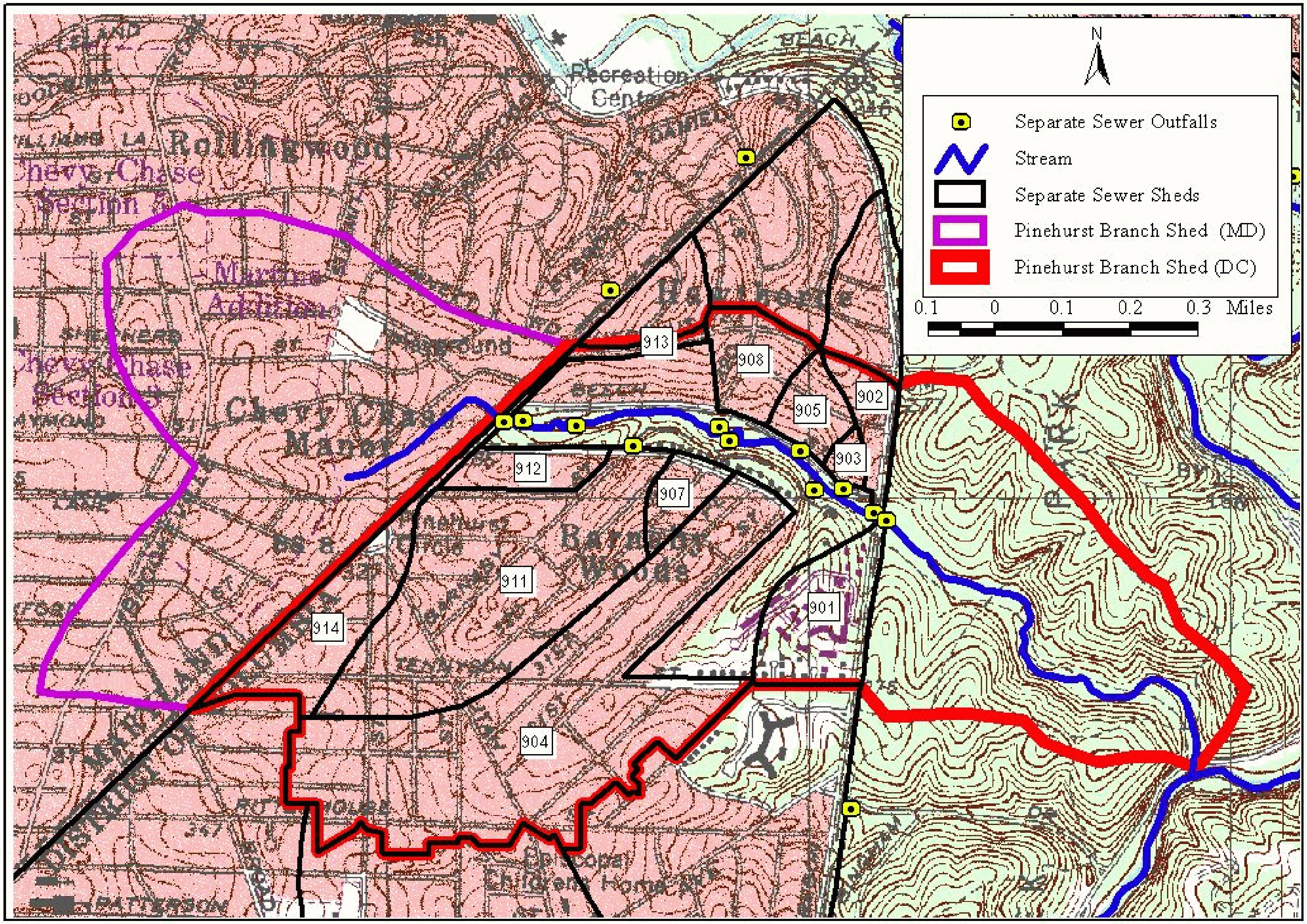

Figure 23. Pinehurst Branch Sub-Shed

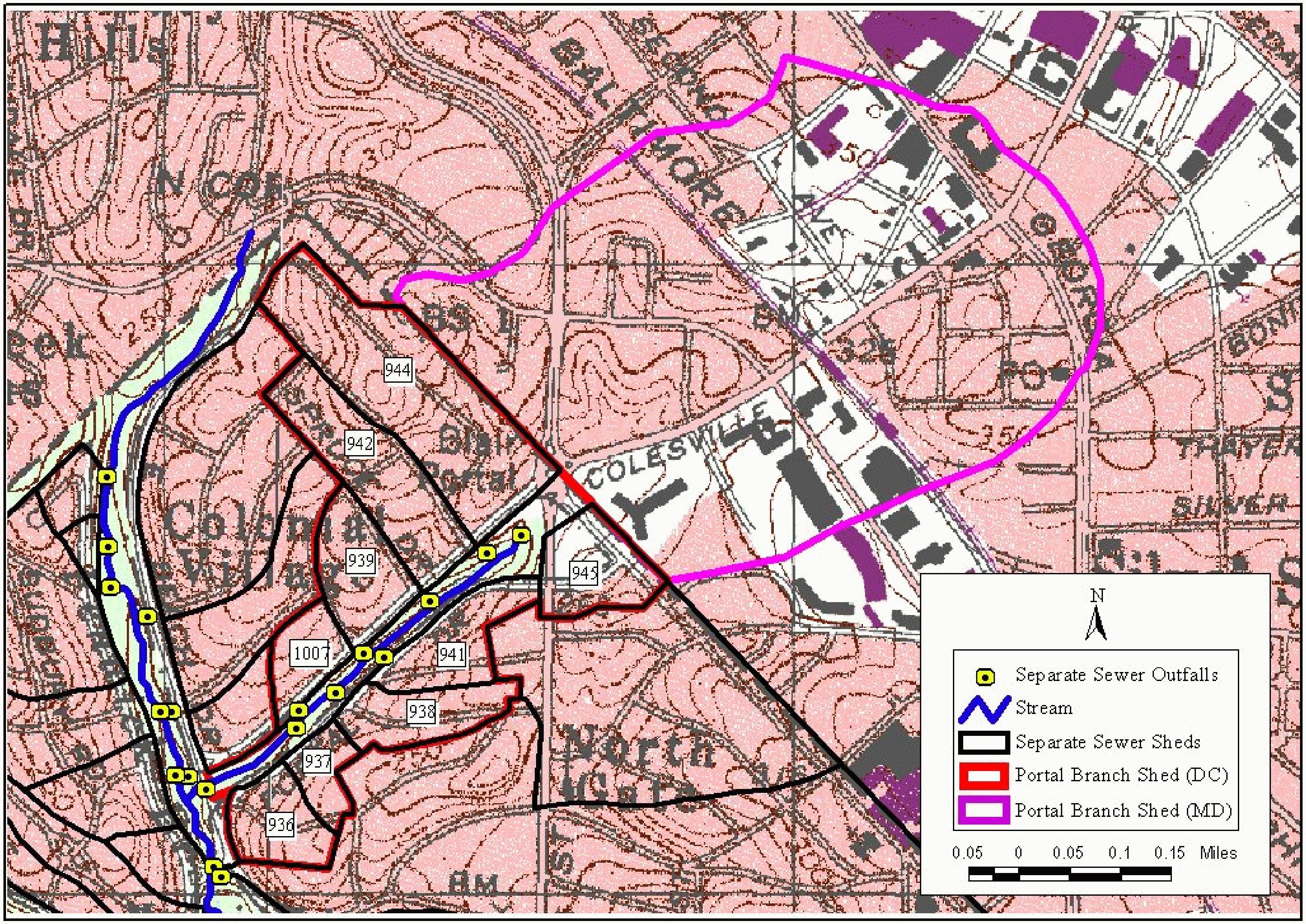

Figure 24. Portal Branch Sub-Shed

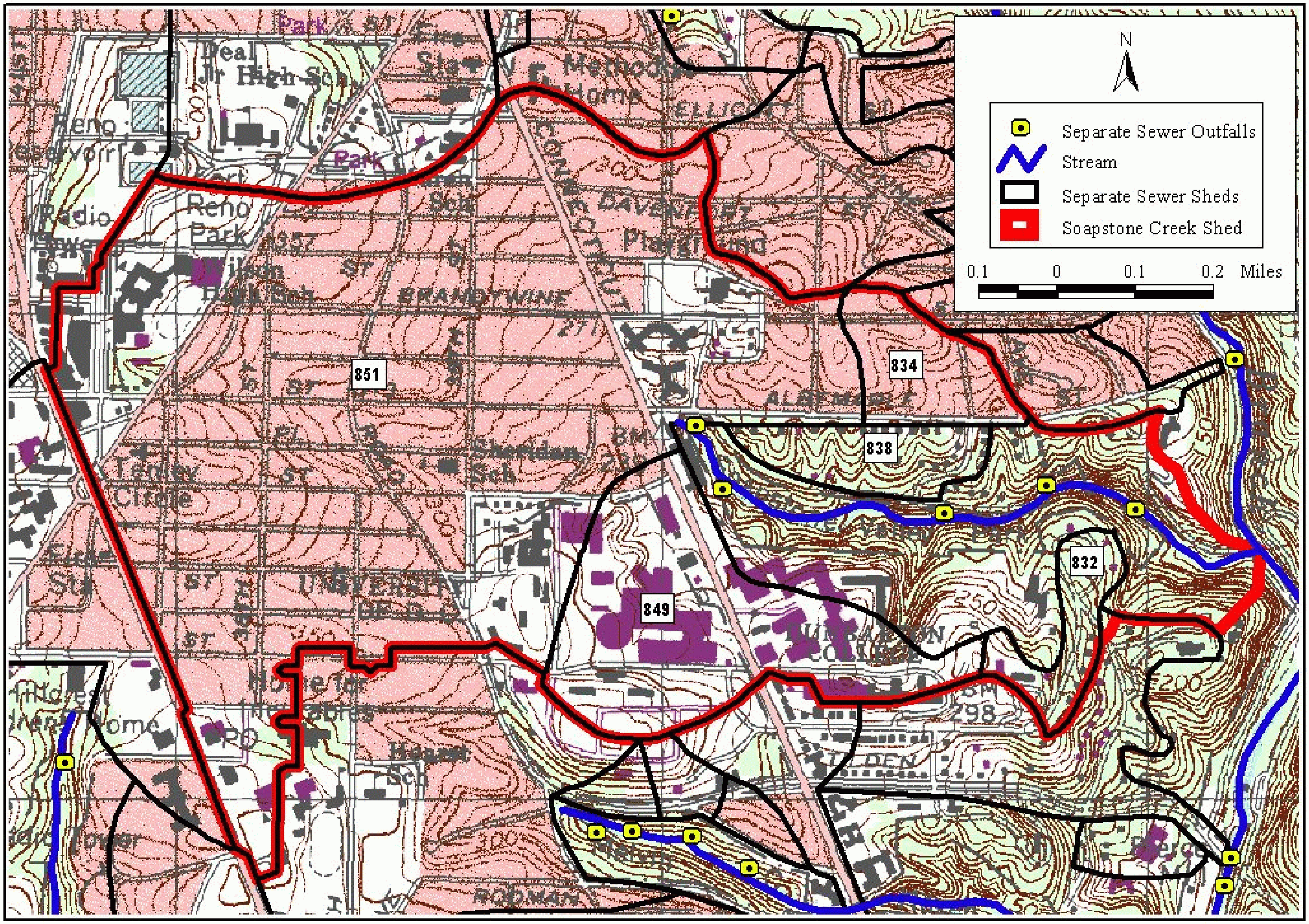

Figure 25. Soapstone Creek Sub-Shed

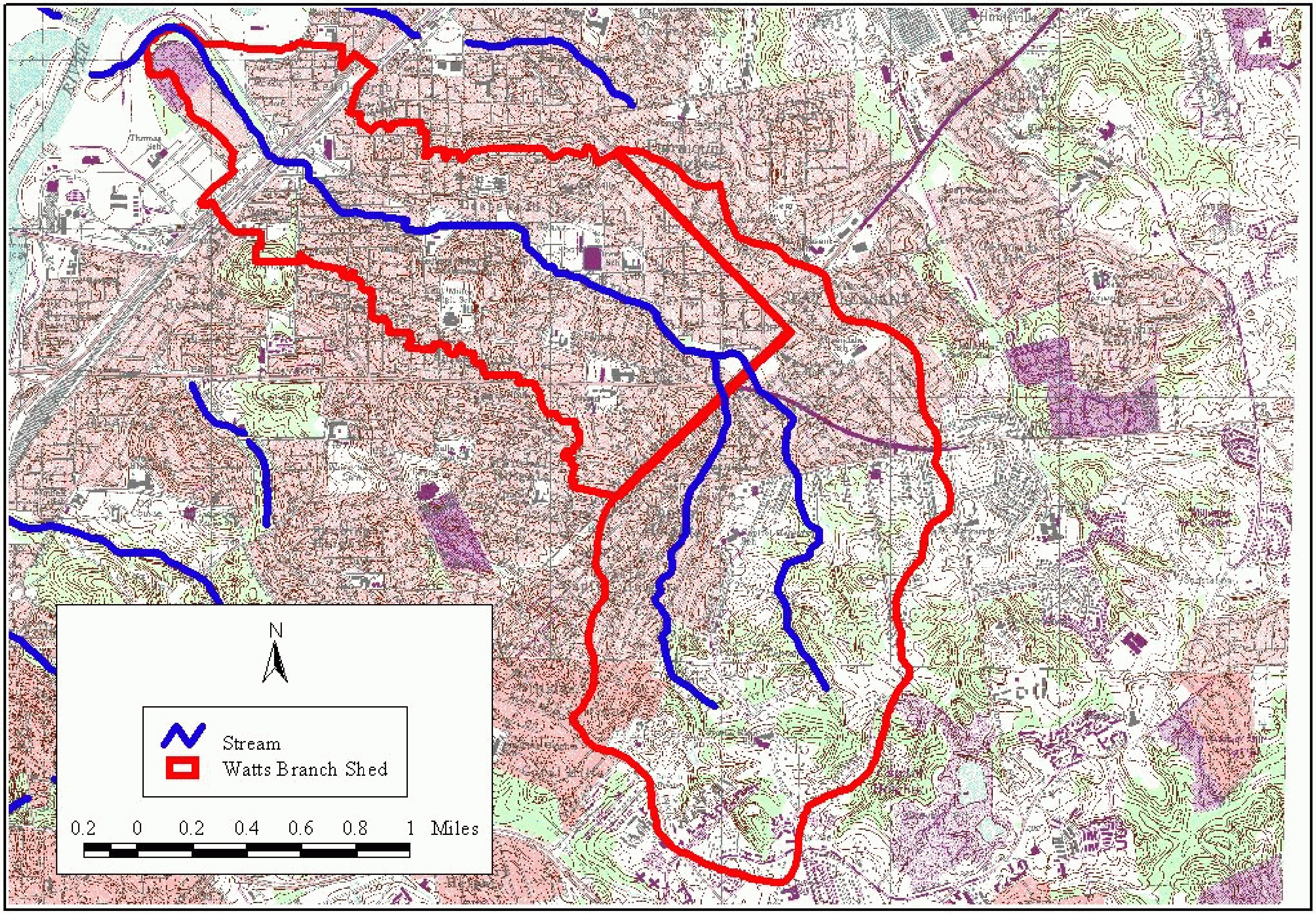

Figure 26. Watts Branch Sub-Shed

III. Model Verification

In this section, results from the DC Small Tributaries TMDL Model are compared with observations in order to assess the ability of the model to predict concentrations of toxic chemicals and fecal coliform in the 23 small tributaries. As discussed in Section I, the only data currently available for model verification are data for metals and fecal coliform, primarily from the DC DOH routine monitoring program. The DC DOH data set only contains values for total (= dissolved + particulate) metals. In the case of Hickey Run, there are some additional data available for metals and fecal coliform in 1999 and 2000 from the DC WASA LCTP monitoring program. The LTCP Hickey Run sampling location was a sewer pipe not far from the location of the outfall discharging into the above-ground portion of the stream (DC WASA 2000a). Though arsenic concentrations are also reported in these two data sets, they are not used in this report because all reported arsenic values are below the laboratory quantification limit. In Figures 27 through 38, model predictions for total zinc, total lead, total copper, and fecal coliform are compared with available data for the time period, January 1999 through July 2000 for the three tributaries for which the most data is available, Hickey Run, Watts Branch, and Battery Kemble/Fletchers Run. In these figures, model predictions are represented by diamonds and measured data are represented by squares. On days in which data are available for comparison, matching model predictions are represented by filled diamonds. For data results reported as less than the laboratory quantification limit (ql), values of (½* ql) were used.

The metal for which the best data are available is zinc. Observed zinc values in the DC DOH routine monitoring program data set are almost always above the laboratory ql, which is usually 20 μg/L. From Figures 27, 31, and 35, it can be seen that the model is reasonably successful in predicting concentrations of total zinc in Hickey Run, Watts Branch, and Battery Kemble Creek. Though the model fails to come close to predicting an extremely high zinc concentration measured in a Hickey Run sample collected on 2/18/2002, apart from this potential outlier, predicted zinc concentrations are reasonably close to observed concentration on the majority of days in which data is available. Lead and copper concentrations in the DC DOH data set are most often reported as less than the ql, which is usually 5 μg/L for lead and 10 or 25 μg/L for copper, making these data less useful for comparison with model predictions. From Figures 28, 29, 32, 33, 36 and 37 it is clear that though the model predictions for lead and copper match available data points fairly well in many cases, the model fails to predict a number of high concentrations measured in early 2000. A limitation of the model is the fact that the maximum concentrations that can be predicted for these metals are the input storm concentrations, given in Table 2b, which represent estimates of the city-wide storm water average concentrations. Tables 7 through 9 contain results of a comparison of model predictions for metals with available monitoring data for the time period, January 1995 through July 2000 for twelve tributaries for which data were available. The second column of these tables gives the number of available data points (and matched model prediction points) used in the comparison, the fifth column gives the average of the difference between model predictions (on the date of the observation) versus observed values, and the last column gives the average of the absolute value of the difference between model predictions and observed values. These results indicate that the model is under-predicting metals concentrations in these streams. The average of predicted metals concentrations is, very roughly, on the order of half of the average of observed metals concentrations in these streams, where the model averages are only for days in which data are available.

Predicted versus observed fecal coliform concentrations for Hickey Run and Watts Branch are shown in Figures 30, 34, and 38. In the DC DOH data set, the minimum quantification limit for fecal coliform is generally 20 counts/100 mL and the maximum quantification limit is 160,000 counts/100 mL. In these two figures, it can be seen that observed concentrations are at times much higher than the model's estimated storm concentration of 17300 counts/100 mL, and therefore that the model sometimes seriously under-predicts fecal coliform concentrations. A limitation of the model is the fact that the maximum concentration that can be predicted for fecal coliform is the input storm concentration, given in Table 2c, which represent an estimate of the city-wide storm water average concentration. However, results in Table 10 show that for some streams, considering only days in which data are available, the average of the model predictions are higher than the average of the data values.

Table 7. Comparison of Model Predictions for Total Zinc Versus 1995-2000 Data

Tributary	Number of Zn Data Points	Zn Data Average (µg/L)	Zn Model Average (µg/L)	Average Error (µg/L)	Average Absolute Error (µg/L)
Battery Kemble	15	16.1	12.9	3.3	14.3
Fort Dupont	10	35.1	21.0	14.1	32.7
Fort Chaplin	13	59.0	19.2	39.8	54.0
Fort Davis	14	35.8	17.9	17.9	31.6
Fort Stanton	12	43.4	21.0	22.4	49.0
Foundry Br	10	46.6	7.5	39.1	39.1
Hickey Run	19	72.2	47.5	24.6	41.0
Nash Run	9	86.7	7.5	79.2	79.2
Piney Br	5	24.6	63.3	-38.7	51.8
Popes Br	8	37.3	27.4	9.8	46.1
Texas Ave Trib	12	69.5	20.9	48.6	72.6
Watts Br	15	42.1	19.7	22.4	24.2

Table 8. Comparison of Model Predictions for Total Lead Versus 1995-2000 Data

Tributary	Number of Pb Data Points	Pb Data Average (µg/L)	Pb Model Average (µg/L)	Average Error (µg/L)	Average Absolute Error (µg/L)
Battery Kemble	15	3.8	1.5	2.3	3.9
Fort Dupont	9	3.4	3.2	0.3	4.4
Fort Chaplin	12	3.3	2.8	0.5	4.0
Fort Davis	12	4.1	2.7	1.4	4.7
Fort Stanton	12	4.9	2.9	2.0	5.7
Foundry Br	9	6.6	0.6	6.0	6.0
Hickey Run	18	13.9	7.9	6.1	10.6
Nash Run	8	3.9	0.6	3.3	3.3
Piney Br	5	4.8	10.2	-5.4	6.9
Popes Br	9	7.9	3.6	4.2	9.8
Texas Ave Trib	12	4.6	2.9	1.7	5.9
Watts Br	15	5.7	2.7	3.0	3.5

Table 9. Comparison of Model Predictions for Total Copper Versus 1995-2000 Data

Tributary	Number of Cu Data Points	Cu Data Average (μg/L)	Cu Model Average (μg/L)	Average Error (μg/L)	Average Absolute Error (μg/L)
Battery Kemble	15	11.5	5.2	6.3	9.5
Fort Dupont	9	13.7	8.3	5.3	12.1
Fort Chaplin	11	10.1	8.0	2.1	8.1
Fort Davis	13	11.2	7.1	4.0	9.0
Fort Stanton	12	12.3	7.9	4.4	11.6
Foundry Br	10	30.3	3.5	26.8	26.8
Hickey Run	18	20.1	17.2	3.0	13.4
Nash Run	9	10.4	3.5	6.9	6.9
Piney Br	5	7.7	21.5	-13.8	17.4
Popes Br	8	9.3	9.9	-0.7	11.8
Texas Ave Trib	12	11.0	7.8	3.2	11.6
Watts Br	15	12.1	7.4	4.6	8.5

Table 10. Comparison of Model Predictions for Fecal Coliform Versus 1995-2000 Data

Tributary	Number of FC Data Points	FC Data Average (No./100 mL)	FC Model Average (No./100 mL)	Average Error (No./100 mL)	Average Absolute Error (No./100 mL)
Battery Kemble	40	3569	2653	916	4497
Dalecarlia Trib	40	3060	2949	111	3633
Fenwick Br	9	901	1286	-385	647
Fort Dupont	13	371	1920	-1549	1958
Fort Chaplin	17	1191	1088	103	1715
Fort Davis	17	723	1772	-1049	2012
Fort Stanton	15	649	2616	-1967	2335
Foundry Br	35	35799	3517	32282	32777
Hickey Run	60	9664	3024	6640	8859
Nash Run	15	12421	733	11688	11825
Popes Br	16	2264	2702	-439	3221
Texas Ave Trib	16	16079	3281	12798	17131
Watts Br	56	8535	2065	6470	8621

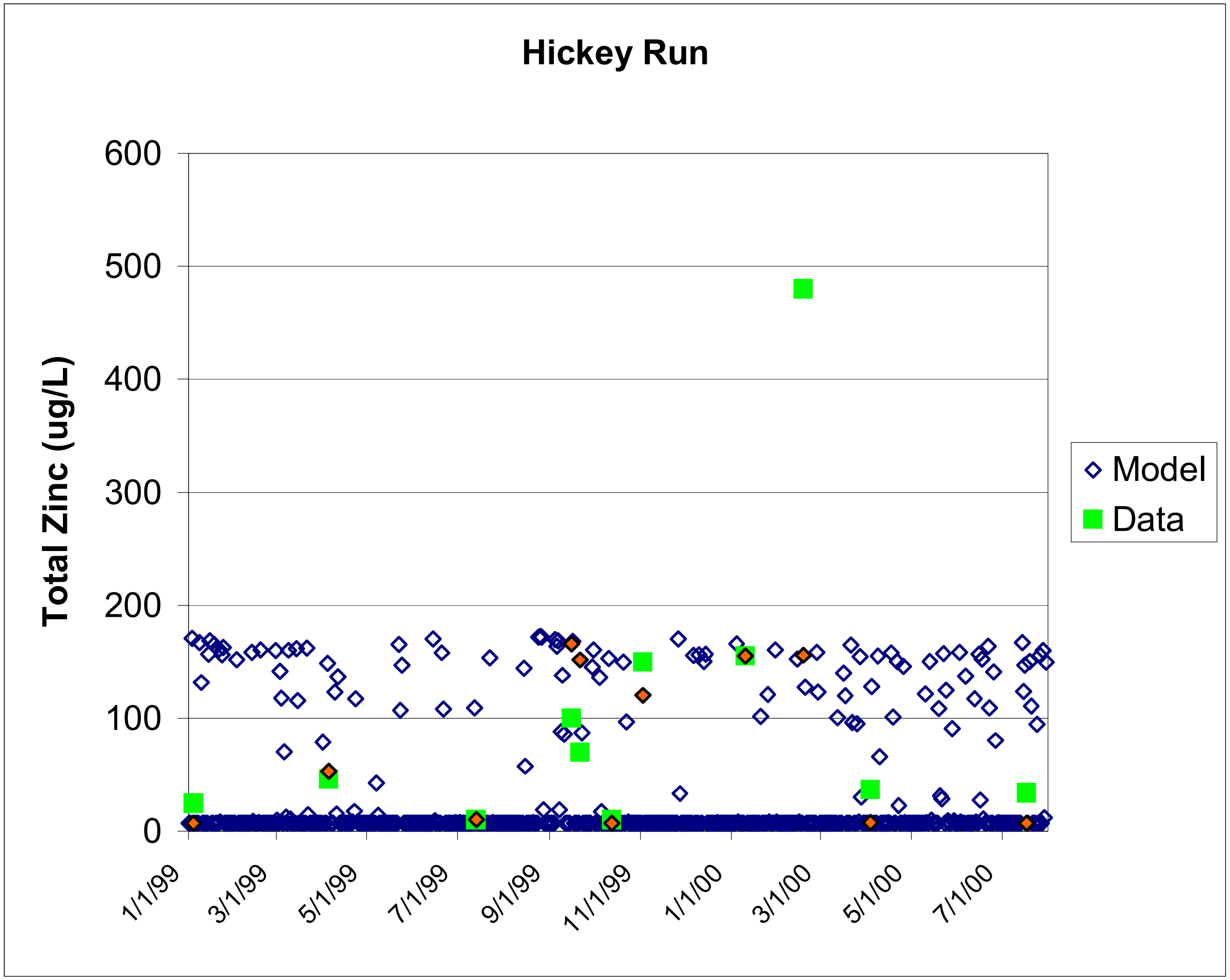

Figure 27. Model Predictions Compared with Measured Values for Zinc in Hickey Run

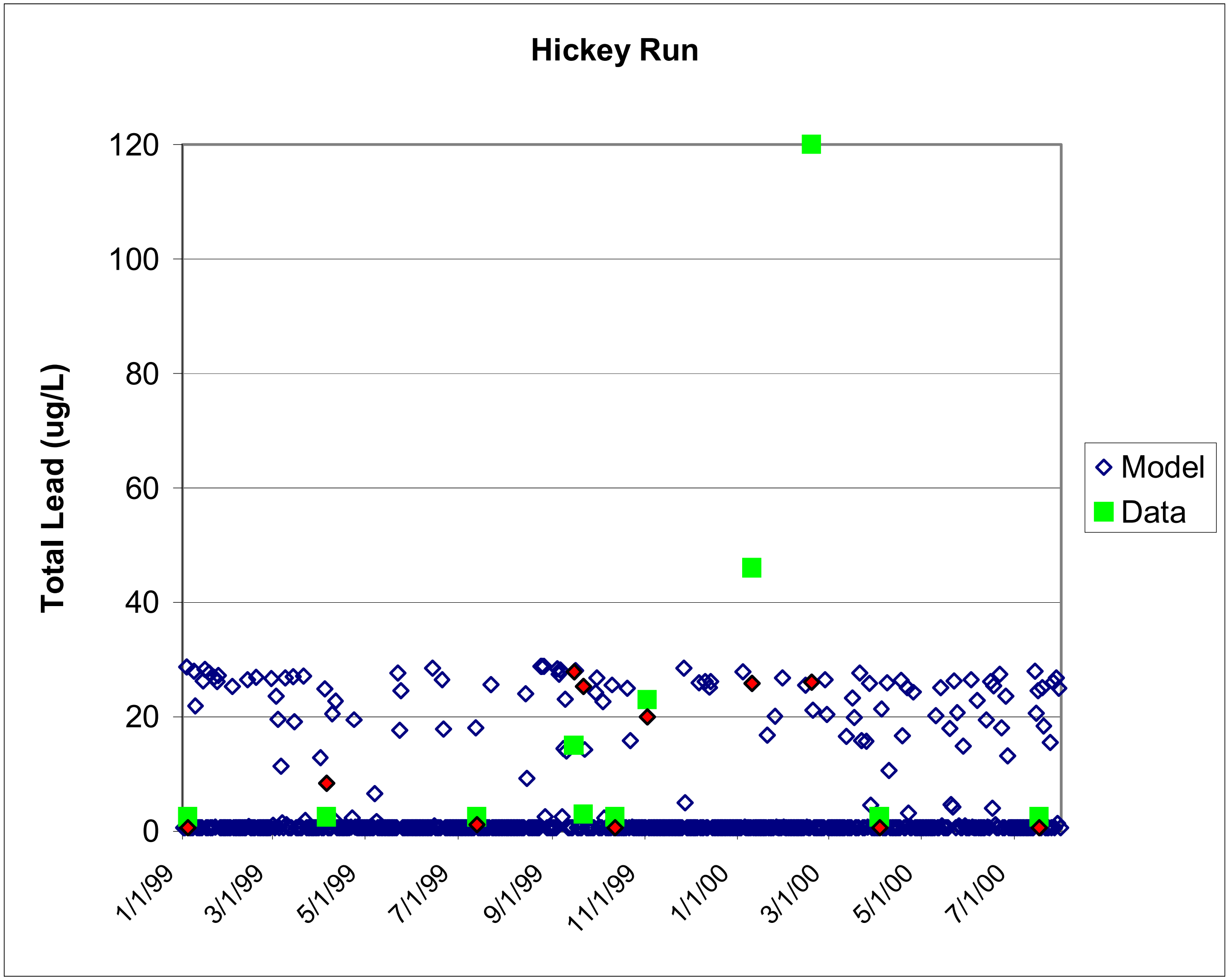

Figure 28. Model Predictions Compared with Measured Values for Lead in Hickey Run

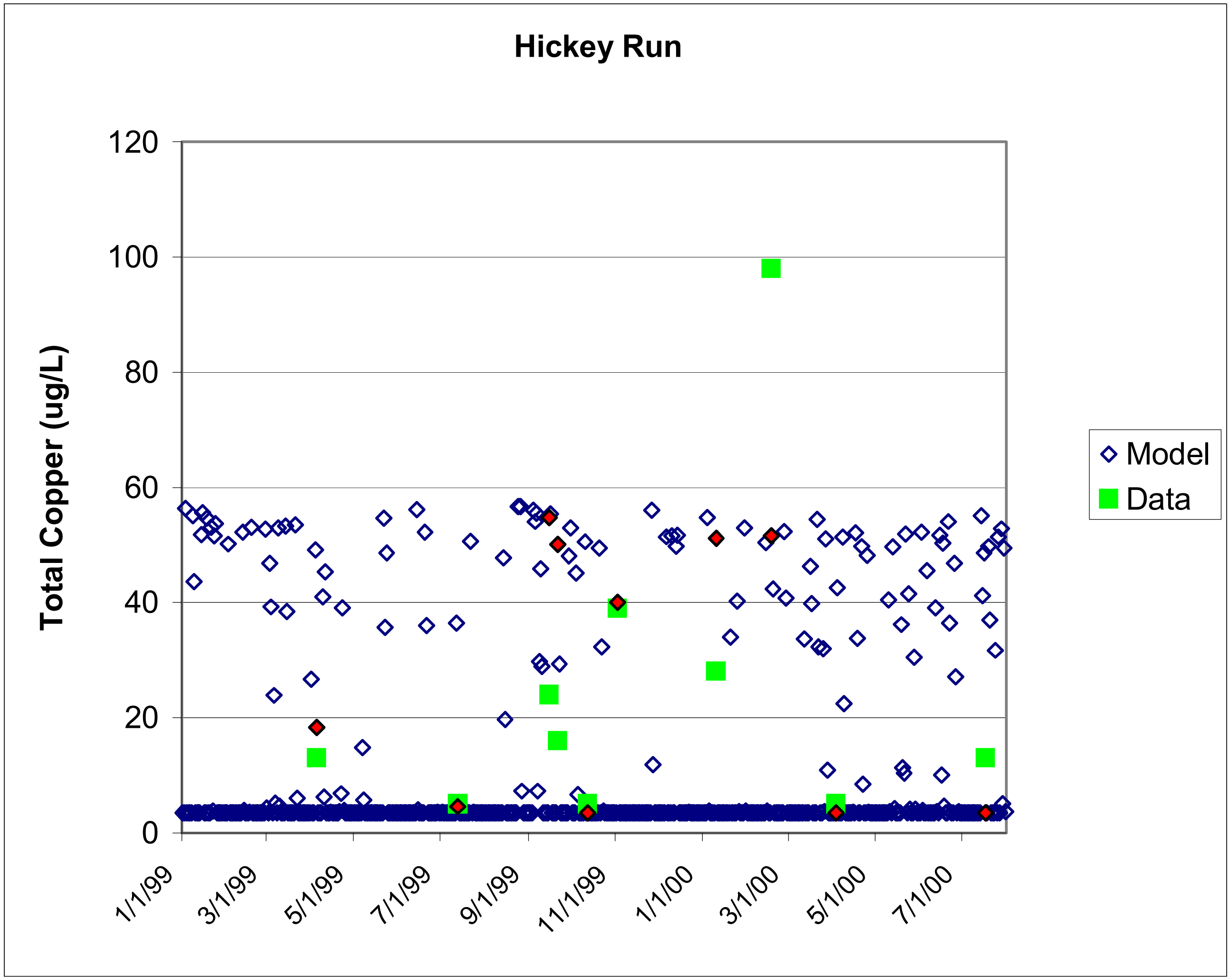

Figure 29. Model Predictions Compared with Measured Values for Copper in Hickey Run

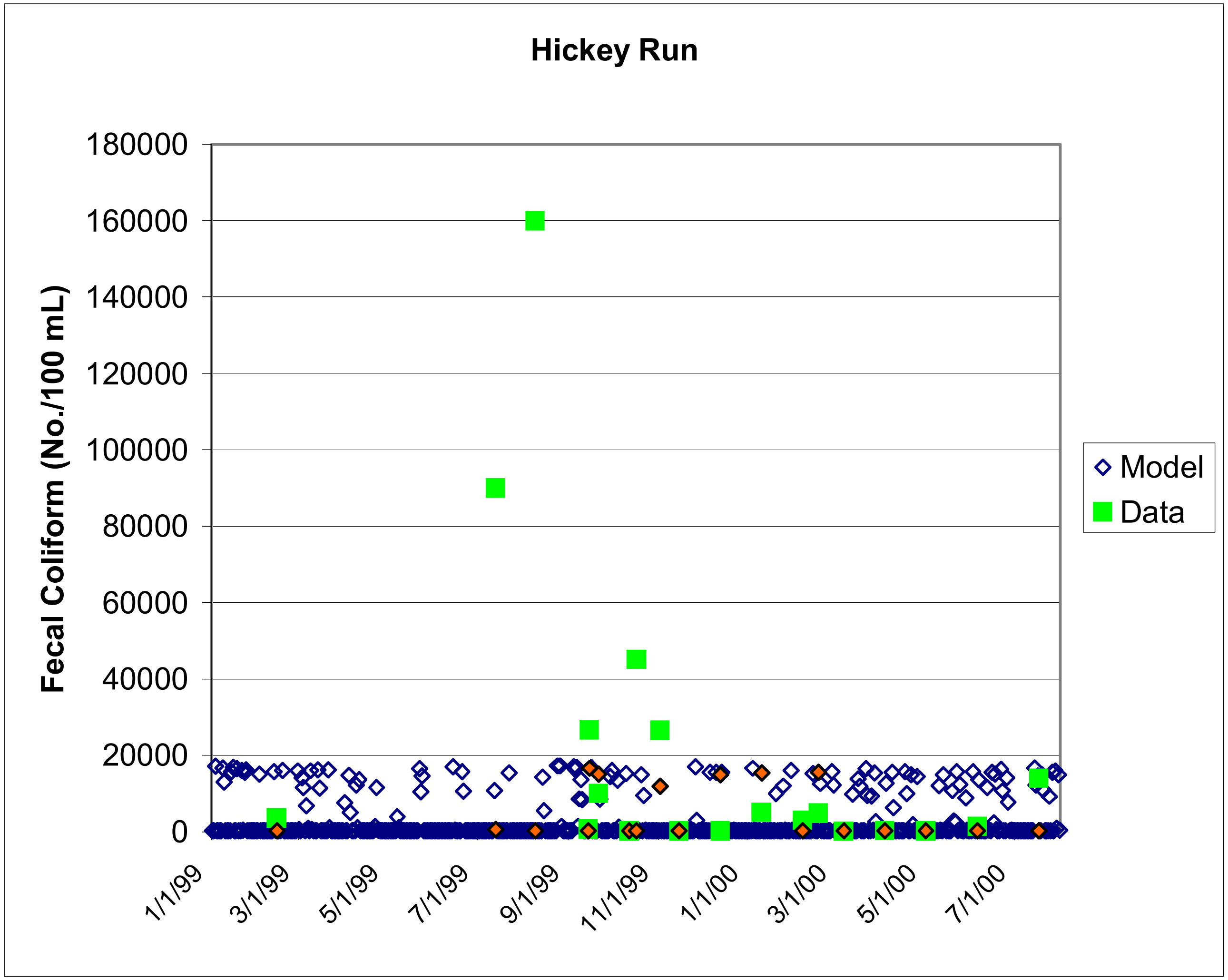

Figure 30. Model Predictions Compared with Measured Values for Fecal Coliform in Hickey Run

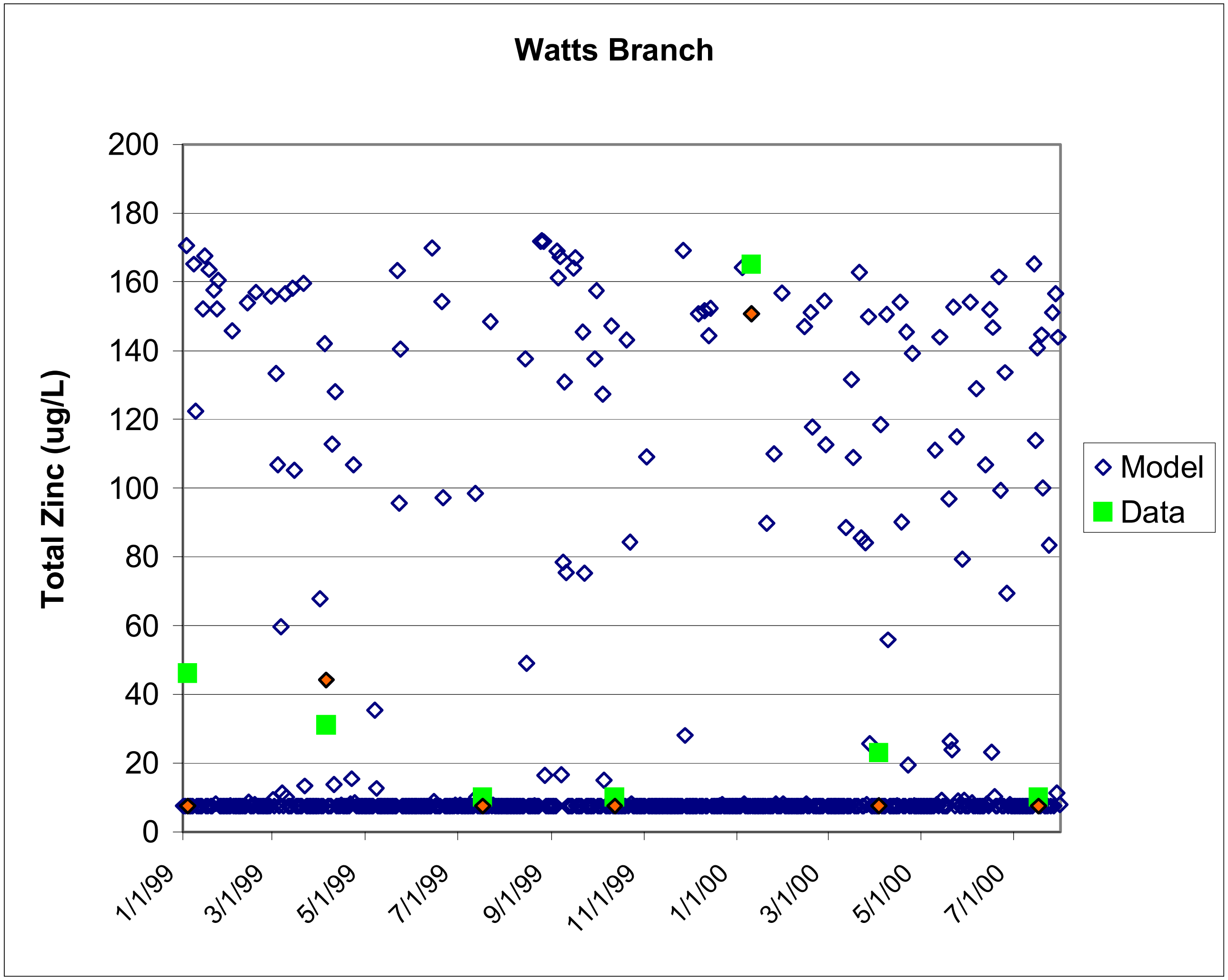

Figure 31. Model Predictions Compared with Measured Values for Zinc in Watts Branch

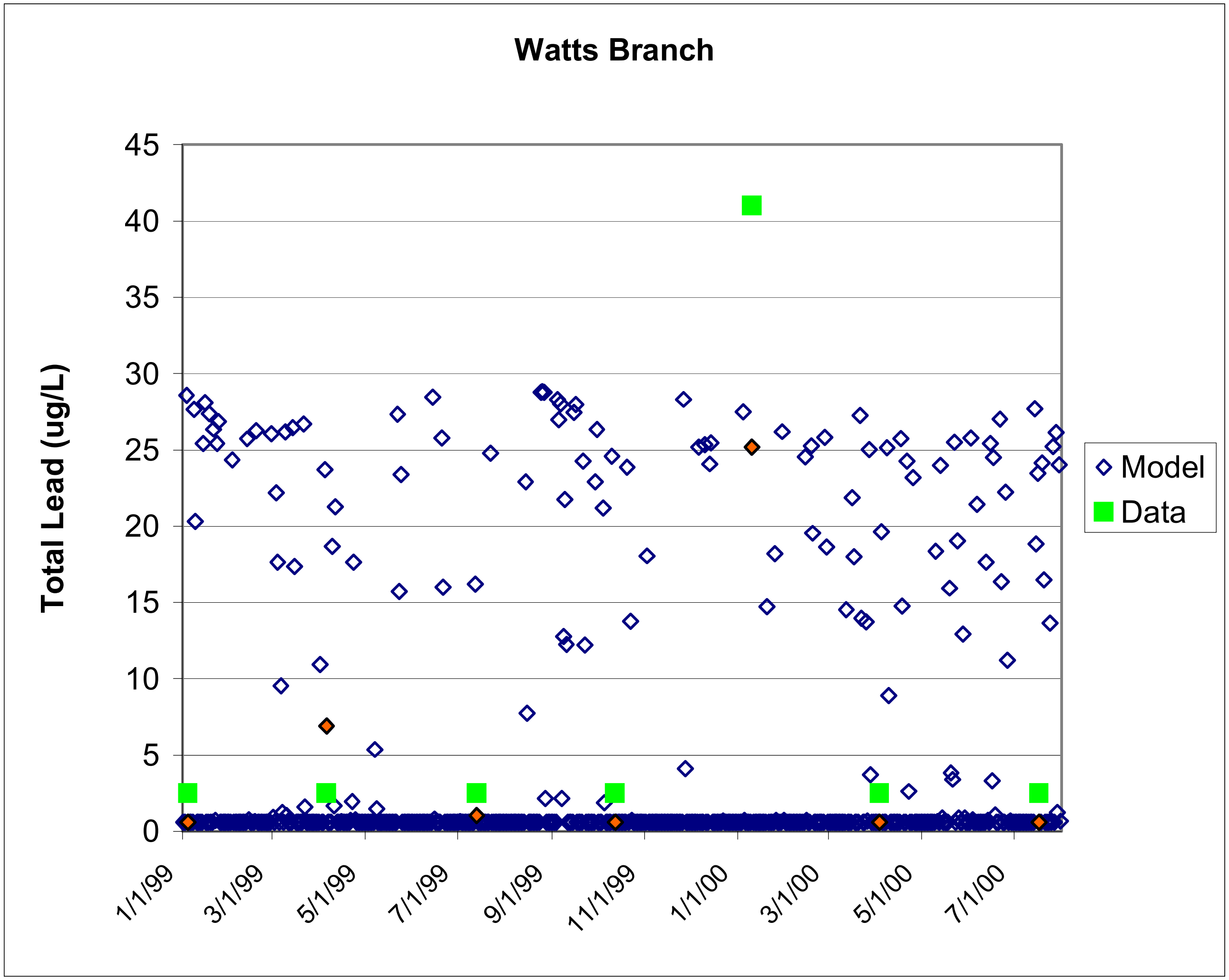

Figure 32. Model Predictions Compared with Measured Values for Lead in Watts Branch

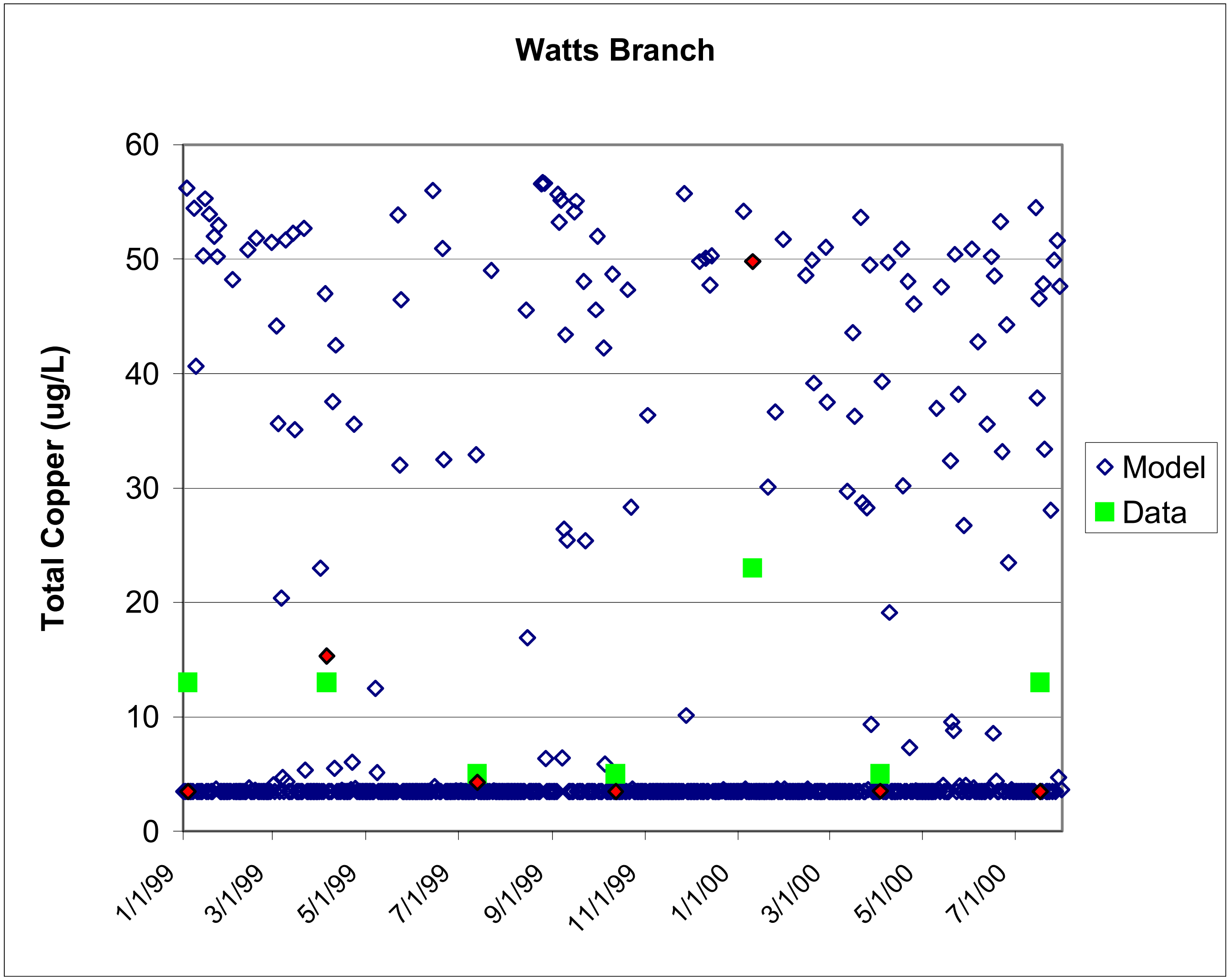

Figure 33. Model Predictions Compared with Measured Values for Copper in Watts Branch

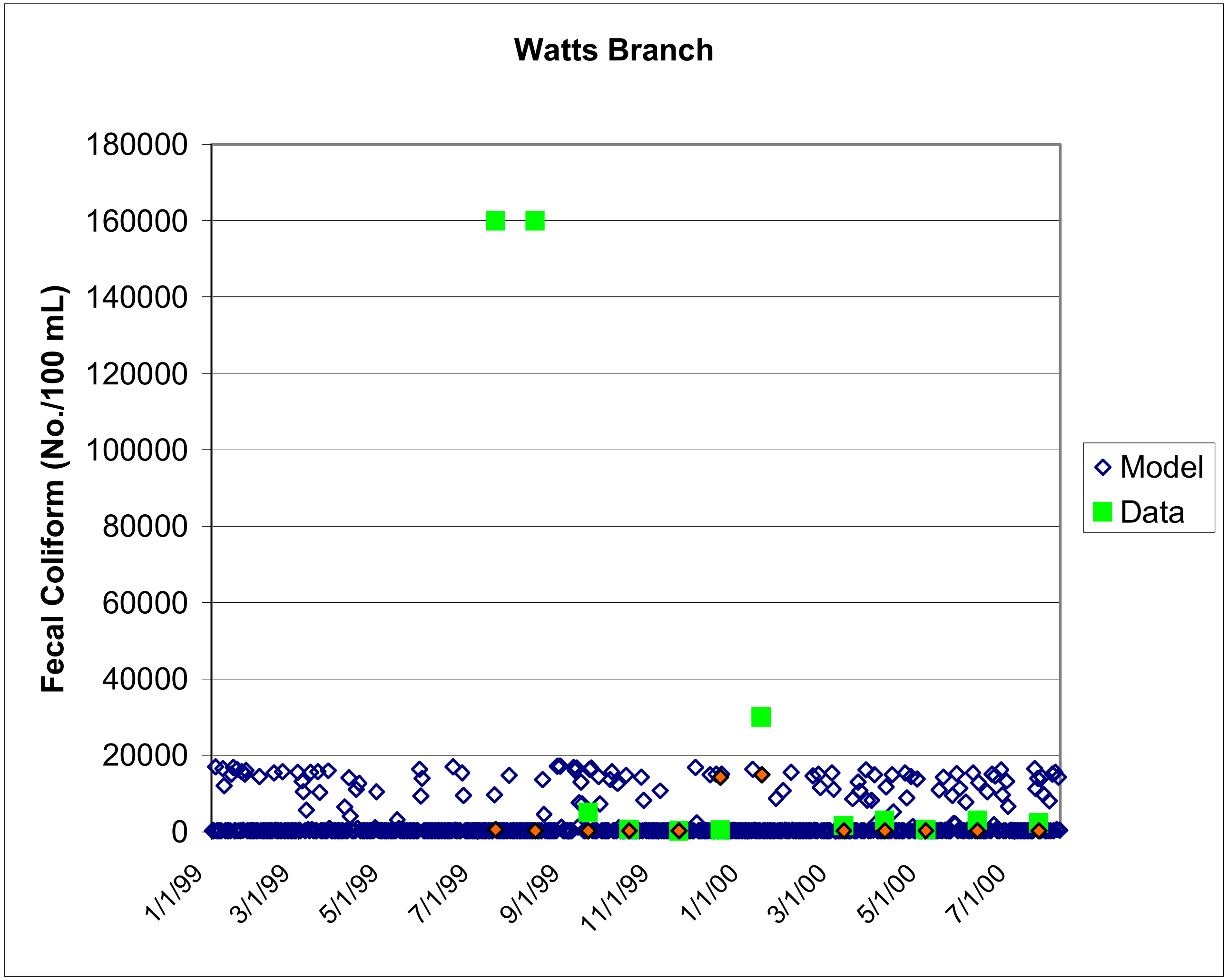

Figure 34. Model Predictions Compared with Measured Values for Fecal Coliform in Watts Branch

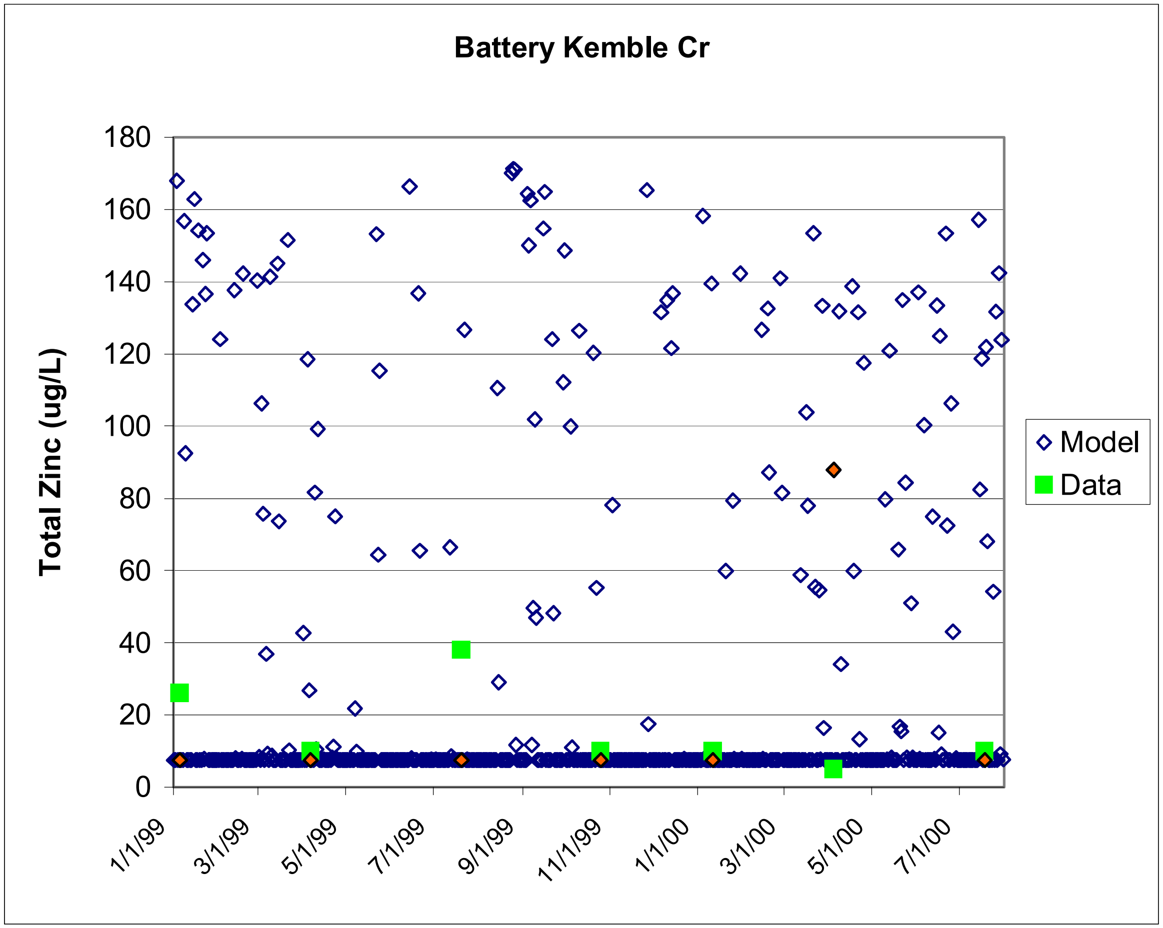

Figure 35. Model Predictions Compared with Measured Values for Zinc in Battery Kemble Creek

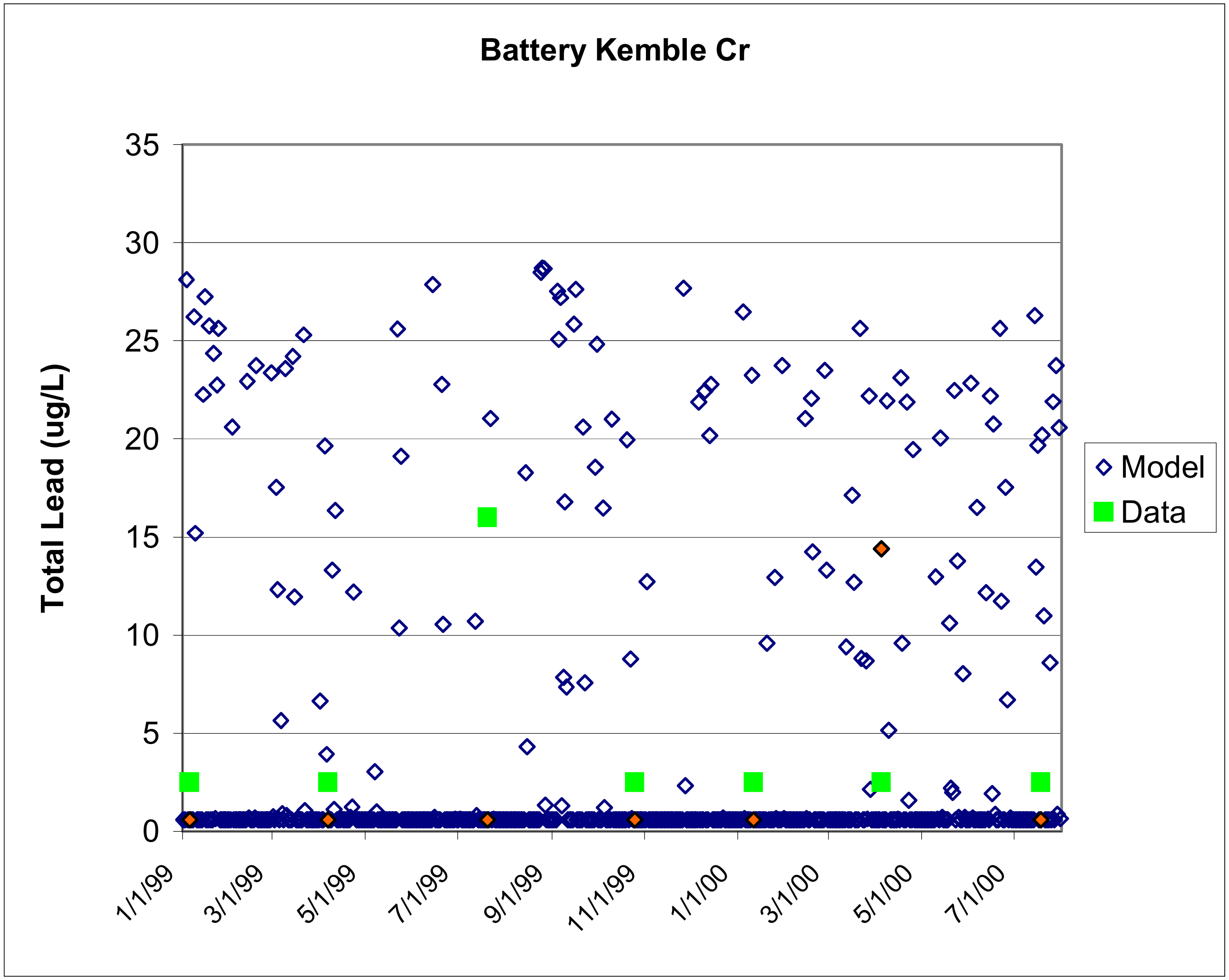

Figure 36. Model Predictions Compared with Measured Values for Lead in Battery Kemble Creek

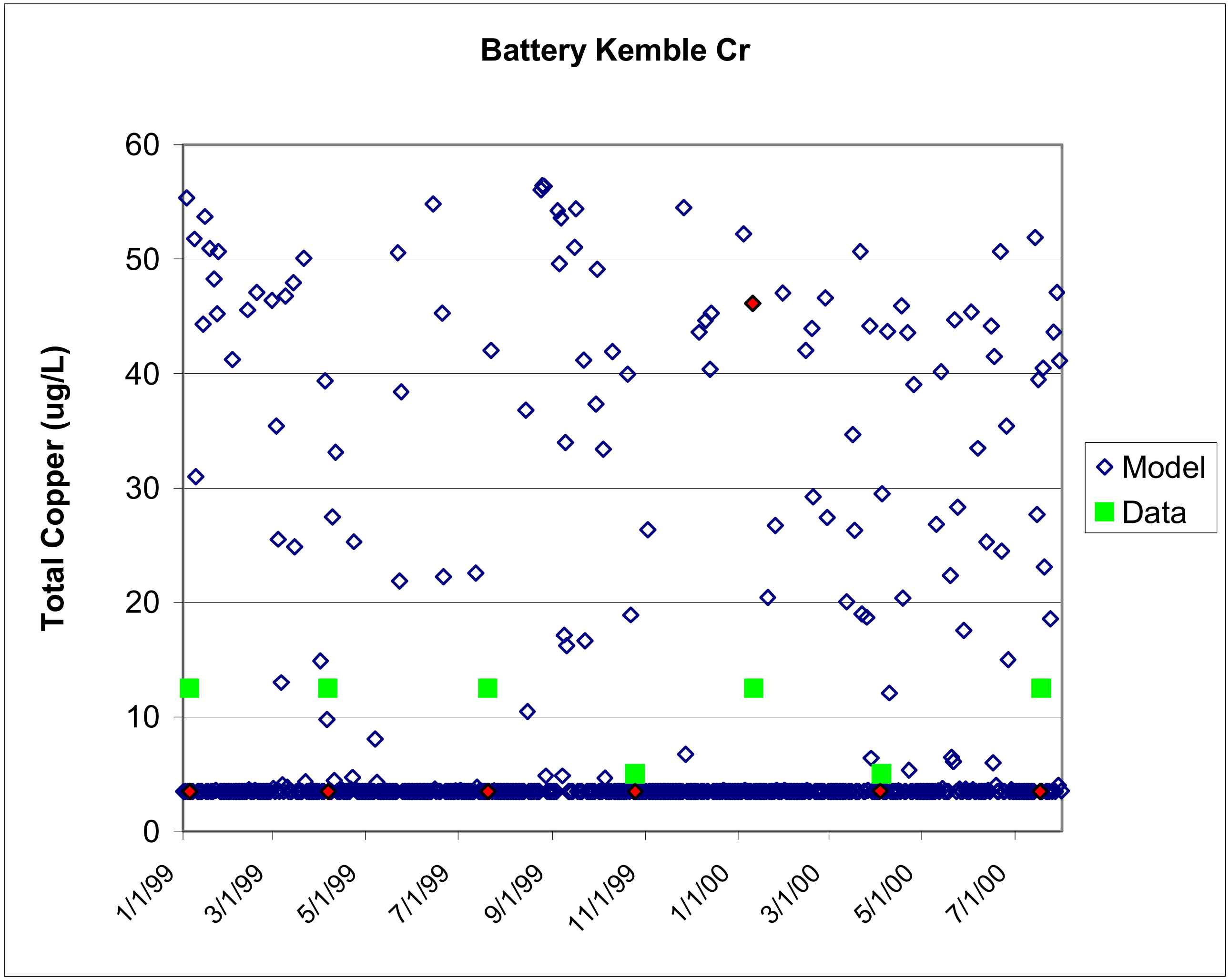

Figure 37. Model Predictions Compared with Measured Values for Copper in Battery Kemble Creek

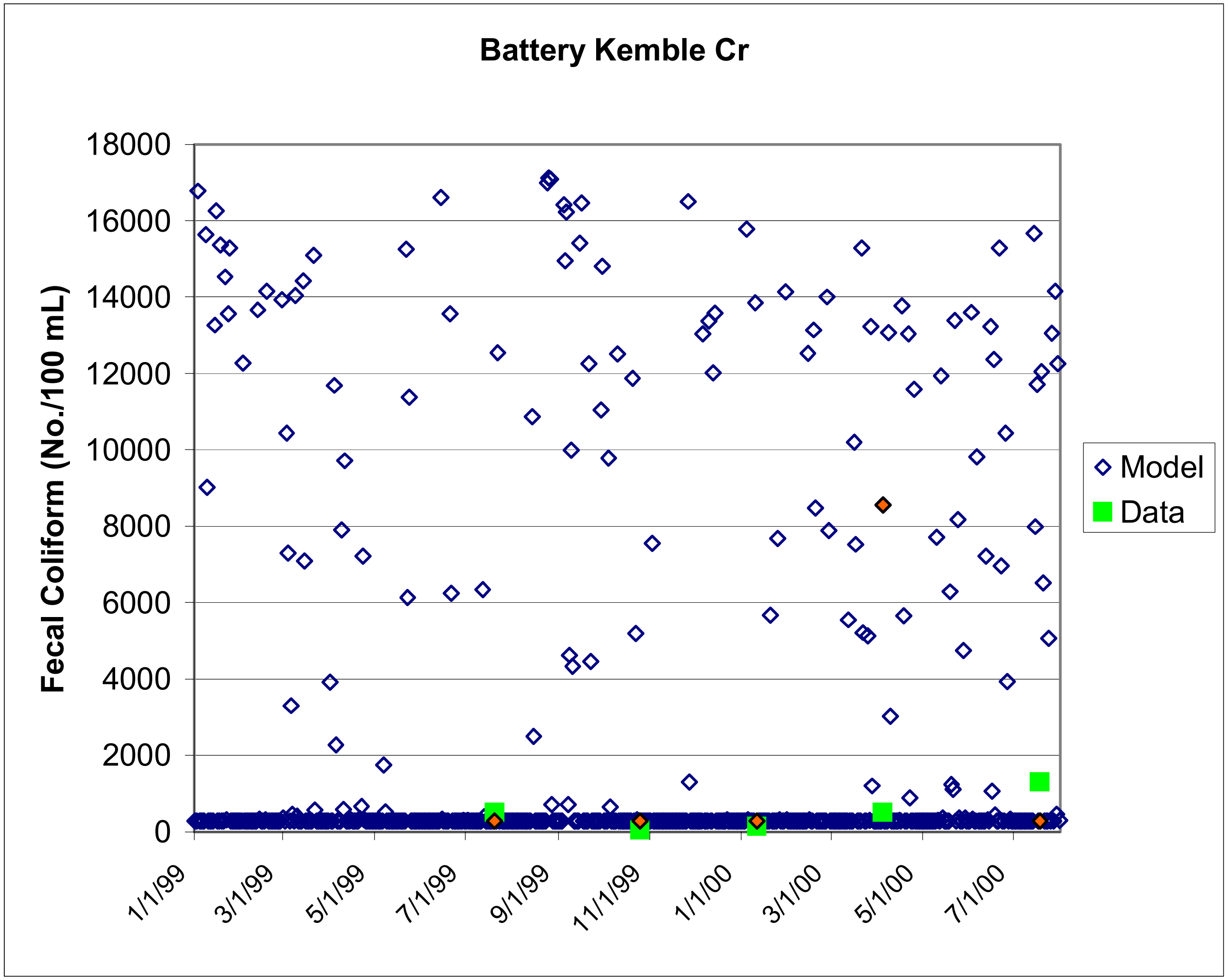

Figure 38. Model Predictions Compared with Measured Values for Fecal Coliform in Battery Kemble Creek

VI. Conclusion

The DC Small Tributary TMDL Model does a fair job in simulating daily concentrations of modeled constituents, based on comparisons of model results with available data. In the plots of predicted versus observed concentrations of zinc, lead, copper, and fecal coliform for Hickey Run, Watts Branch, and Battery Kemble Creek, the three streams for which the most data are available, model predictions fall reasonably close to observed values for the majority of the data points (Figures 27 - 38). However, the model is unable to simulate the higher concentration values reported in the available data sets. Also, when model results were compared with available data for January 1995 through July 2000, model errors were found to be fairly significant (Tables 7 - 10).

Because of the limited amount of data for the 23 tributaries listed in Table 1, several significant simplifications have been made which contribute to errors in the model's predictive capabilities. A primary source of error is the fact that the model uses, for each constituent, a single value for the storm water concentration (and a single value for the base flow concentration) assumed to be the same for all streams for all storms. Clearly, in reality, concentrations of pollutants in storm water runoff vary from storm to storm, depending on factors such as the intensity and duration of the storm event, and the amount of time that has elapsed since the last storm. Also, average concentrations of pollutants in storm water are likely to vary from stream to stream depending on conditions and activities in each stream's sub-shed. Another potentially significant source of error is the fact that the process of resuspension of contaminated stream bed sediments during storm flows is not simulated by the model.

Additional data would improve our understanding of toxic chemicals in the District's small tributaries. Collection of the following data would be useful in determining whether or not District Water Quality Standards are being met and would support the development of more accurate predictive models:

- several bed sediment samples collected from each small tributary and analyzed for toxic chemicals
- water column samples collected from each small tributary during 5 or more storm and 5 or more non-storm events, analyzed for toxic chemicals, using laboratory detection limits below District Water Quality Standards
- storm water monitoring data at additional locations in the city in order to support the development of a regression model predicting storm water constituent concentrations base on sub-shed land use, and on storm intensity

REFERENCES

Banta, W.C. 1993. Biological Water Quality of the Surface Tributary Streams of the District of Columbia. Occasional Publication of the Department of Biology, American University Volume 2 Number 1. American University, Washington, DC.

Behm, P., A. Buckley, C.L. Schultz. 2003. TAM/WASP Toxics Screening Level Model for the Tidal Portion of the Anacostia River - Final Draft. Prepared by the Interstate Commission on the Potomac River Basin for the District of Columbia Department of Health, Washington, DC.

DC WASA. 2000a. Study Memorandum 5-5A: CSS and SSWS Monitoring Results - August 1999 - February 2000. District of Columbia Water and Sewer Authority EPMC III - Sewer Systems; Greeley and Hansen - Program Manager. Washington, DC.

DC WASA. 2000b. Study Memorandum 5-5B: CSS and SSWS Monitoring Results - March - July 2000. District of Columbia Water and Sewer Authority EPMC III - Sewer Systems; Greeley and Hansen - Program Manager. Washington, DC.

DC WASA. 2000c. Study Memorandum LTCP-5-8: CSS and SSWS Event Mean Concentrations - Draft. District of Columbia Water and Sewer Authority EPMC III - Sewer Systems. Program Manager - Greeley and Hansen. September 2000.

DC WASA. 2002. Combined Sewer System Long Term Control Plan. Prepared by Greeley and Hansen, LLC for the District of Columbia Water and Sewer Authority.

Gruessner, B., D.J. Velinsky, G.D. Foster, J. Scudlark, R. Mason. 1998. Dissolved and Particulate Transport of Chemical Contaminants in the Northeast and Northwest Branches of the Anacostia River. Revised April 1998. Interstate Commission on the Potomac River Basin Report 97-10. ICPRB, Rockville, MD.

Karickhoff, S.W. 1984. Organic Pollutant Sorption in Aquatic Systems. J. Hydraul. Eng. Div. ASCE. Vol. 110, p. 707.

LTI. 1995. Documentation Report District of Columbia NPDES Part II Storm Water Permit Application GIS Coverages. Prepared for Peer Consultants by Limno-Tech, Inc., Washinton, DC.

Mandel, R., and C.L. Schultz. 2000. The TAM/WASP Model: A Modeling Framework for the Total Maximum Daily Load Allocation in the Tidal Anacostia River - Final Report. Prepared by the Interstate Commission on the Potomac River Basin for the District of Columbia, Department of Health, Environmental Health Administration. Washington, DC.

U.S. Census Bureau. 2002. State and County QuickFacts. Data derived from Population Estimates, 2000 Census of Population and Housing.